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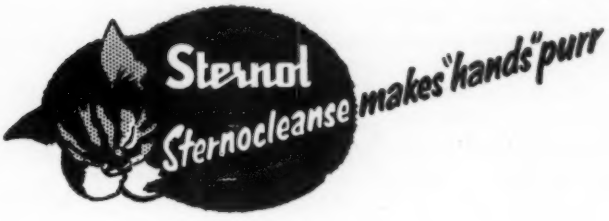

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APPLICATION OF A NEW ERGOMETER TO DEVELOP A LABORATORY TEST FOR WORK CAPACITY

WITH FURTHER APPLICATION TO COMPARISONS OF TEN-YEAR-OLD CHILDREN IN LONDON AND SYDNEY*

BY

THE LATE FRANK S. COTTON

Department of Physiology, University of Sydney

PRESENT-DAY ERGOMETERS AND THEIR DEFECTS

Human ergometers in the past have developed through a number of stages, from that devised by Martin (1914) to that of Hudson, Boys, and Williams (1953).

The ergometer (Fig. 1) measures the work done against a resistance according to the formula—Work = Force × Distance. When the wheel is turned in the direction indicated by the arrow, the weight is lifted and the reading on the spring balance is decreased. In theory, if the balance reads B pounds and the weight is W pounds, the force resisting the turning of the wheel is $(W - B)$ pounds. The distance traversed in any given run is $R \times C$, where R is the number of revolutions and C is the circumference of the wheel in feet. The work done in foot pounds is then $(W - B)\ R.C$. In practice, however, the coefficient of friction of any band alters substantially from day to day according to temperature and humidity and from minute to minute in use. Consequently, standardization and prediction are impossible.

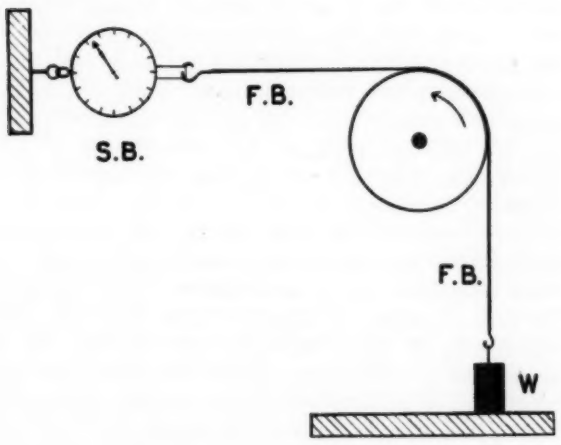


FIG. 1.—Martin ergometer for measuring human work capacity.
S.B. Spring balance.
F.B. Friction band applied to rim of wheel.
W. Weight.

All modern ergometers have been based on some electrical principle, with resulting increase of complexity and cost, but none has solved the problem of securing an accurate constant resistance, or of obtaining the result quickly. Even the best types, such as that described by Kelso and Hellebrandt (1934), still depend on the recording of some graphical area which must subsequently be measured, *e.g.* by means of a planimeter. This requires a substantial period to determine the result of each experiment—perhaps 15 minutes or so.

The new ergometer employs a device which simplifies construction, greatly refines the accuracy of measurement, and saves time in calculation. This device provides the means of automatically maintaining constant the resisting force or load initially decided upon for any given experiment. This ergometer is described more fully in Appendix A (Fig. 7, page 177).

APPLICATION OF THE NEW ERGOMETER TO TESTS FOR WORK CAPACITY

The time chosen for each test was 15 seconds, since 10 seconds is too short to give sufficiently accurate results and 20 seconds is too long to permit the necessary repetitions without deterioration of performance.

Since the number of repeated muscular contractions may lie between twenty and forty, the tests measure something intermediate between strength and endurance. Since this is not an individual study but one of groups, no particular advantage is secured by dividing performance by body-weight for individual comparisons. Although this was actually done in all cases and many analyses were made of the data so obtained, these are not relevant to the present communication.

*Most of the expenses in connexion with this research were defrayed by a grant from the National Health and Medical Research Council of Australia.

Five desiderata led to the use of the present ergometer for tests of work capacity:

(1) To develop tests which could be carried out within the laboratory in contrast with those which had been used in the field and were dependent upon unusual facilities and good weather.

(2) To ensure that such tests involved more than one or just a few muscular contractions, in order to avoid the drawbacks inherent in most previous laboratory tests such as the hand grip, Sargent high-jump, etc.

(3) To enable the apparatus to be modified easily and quickly for use on either of the major muscle groups in the body: those concerned with powerful movements of the lower limbs, and those concerned with powerful movements of the upper limbs (involving the arms and shoulders).

(4) To utilize such tests in comparing subjects in different places. It was therefore necessary to ensure that the apparatus could be readily transported.

(5) To obtain a result quickly, since the proposed research would necessitate thousands of repetitions, including rehearsal runs, and preliminary and final tests. With the present device, the number of revolutions is read on the revolution counter when the test is finished, and this is simply multiplied by the value of the resistance and then by a constant factor to give the complete result in foot pounds.

In testing the lower limbs a simple construction like the ordinary bicycle ergometer was used, modified by the automatic device for securing constant resistance. The length of each crank was $6\frac{1}{2}''$, and the flywheel was 21″ in diameter, weighing 78 lb. and spinning 2·56 times with each complete turn of the driving wheel.

In order to convert the apparatus to one suitable for testing the upper limbs, one bicycle pedal was unscrewed, and a freely rotating handle was screwed on in its place so that the "pedals" could be turned as in a mangle, wringer, or cranking mechanism. In practice, the child stands stooping towards the bicycle with feet planted well apart, and steadies himself by grasping firmly the nearly vertical part of the bicycle frame about opposite his left shoulder. He is then in a firm position to rotate the bicycle crank with all the force and speed he can muster. All subjects worked with the right arm only, as it was not possible to use the left arm advantageously. The left-handed subjects are penalized, but it is highly improbable that the group comparisons could be affected.

For purposes of safety a large circular shield was securely placed between the rotating handle and the crank arm normally carrying the pedal. This obviated the possibility that the operator's hand might slip and be damaged by the chain gear. In all the thousands of actual tests no untoward happening of any kind occurred.

Comparable Groups of Children in London and Sydney

The Departments of Education in both cities advised that the 10-year-old group was the best to work with. Above that age children leave the primary school and are separated into groups according to type of education, and below that age co-operation and determination might not be quite so good.

Again, as a result of advice from the Departments of Education in London and Sydney, two schools in each city were selected as representing children from favourable areas (from the parental and social points of view) and two schools as representing children from congested areas.

In the following Figures the groups from the favourable areas are designated by the letter F and those from the congested areas by the letter C.

These schools yielded well over 300 children for London and nearly the same for Sydney. The proportions F to C were much the same in the two places.

In addition an opportunity was afforded to test the boys in an English public school,* Dulwich College, and a Sydney private school,* Knox College.

The parents of the Knox College boys, who represent a more distinguished and materially successful group than those of the children at the schools already classed as favourable, are represented in the Figures by F+. The parents of the boys at Dulwich College represent a still more selective class, and this group is designated by F++.

A group of Sydney girls corresponding to the Knox College boys and given the symbol F+ was tested at the Presbyterian Ladies College, Pymble (P.L.C.). In fact, in many cases, the children attending Knox and P.L.C. came from the same homes.

Children from two additional Sydney schools were also tested; since the general status of these schools was intermediate between F and C just mentioned, they are designated by the letter I (Table I, opposite).

An invariable rule was that all the 10-year-old children on the roll of the school were tested, the only exceptions being absentees or those ineligible through crippling or injury. These were very few in all. In all cases the tests were carried out in comfortable conditions, neither too warm nor too cold, and in all cases excellent working conditions were provided by the schools in question.

*In spite of the opposition of titles these schools correspond in the two cities concerned. They are regarded as more selective than those administered by the Departments of Education in these countries.

TABLE I

GRADING OF SCHOOLS

City		London	Sydney
Schools	F++	Dulwich College (boys)	
	Favourable	Oxford Gardens	Roseville (mixed)
		Franciscan	Wahroonga (mixed)
	F+		Knox College (boys)
			P.L.C. (girls)
	I		Names not given.
	Congested	Sleaford	Redfern
		Deptford	Burke Street

ADMINISTRATION OF THE TESTS AND RESPONSE OF THE CHILDREN

In such tests the result with any one child will vary with the load imposed. To obtain a highly accurate assessment of any individual a series of trials would have to be made to discover the optimum load. Fortunately, the optimum in such tests resembles a plateau rather than a peak and closely concordant results are obtained over quite a range of loads. Hence, it was found that in three well-adjusted trials this optimum was approximated even more closely than required in a group study.

The execution of the test was demonstrated to a group of about eight to ten children and then each was given a rehearsal trial in turn, choosing initially a load appropriate to the weight of each child.

Each test lasted 15 seconds, and was started by the signals—"get ready—go", and stopped by corresponding signals. By recording the results of the rehearsal run, the weight was made nearer the optimum in the first trial run—*e.g.* it was increased if the number of revolutions of the bicycle wheel exceeded a certain value, and decreased if the number was below a second set value. Preliminary work had established that optimum performances were made within the range of 55 to 65 revolutions for the leg test, and 60 to 80 revolutions for the arm test. This, of course, does not represent rate of limb movements, because of the gearing of the bicycle.

To bring the rates of limb movements within these ranges, a second trial run was made, generally with a further small adjustment of the load. The score was taken as the better performance of the two trials. In most cases the second test was the better. If by some mischance the second test fell distinctly below the first, a third trial was given with an intermediate load. When this happened it was generally due to a misjudgment—increasing or decreasing the load too much. In most such cases the best result was obtained with this third trial. It was found that such repetition of trials with a reasonable rest between, entailed no perceptible fatigue, and in fact almost universally the children would plead to "have another go".

INSTRUCTIONS TO THE CHILDREN.—From the outset the writer was aware that differences in performance might result from differences in the conduct of the tests. It was not considered necessary to adhere to a rigid verbal formula for the instructions, but each child was encouraged to put forth his greatest effort.

This latter procedure called for a good deal of extempore stimulating and encouraging remarks, and in general quite a good deal was spoken to the child. Any attempt to replace this by a set of stereotyped instructions would cause the loss of this personal value and would, in the opinion of the writer, yield inferior results. The following gives the general tenor of the instructions:—

(1) *Practice Run.*—You have seen X do this test and I want you all to have a try in turn. You don't need a saddle, you just stand up, like the racing cyclists do—when they race their fastest. This first "go" will not count—it is to help you get used to the machine. I will ask—"Are you all set?"—to start with, and if you say "Yes", I will then say "Get ready—go". I will stop you by saying "Get ready—stop". You can stop at once just as you saw X stop—and don't move again until the flywheel runs down.

(2) *First Trial.*—Now this is a competition: we all want to see how fast you can ride. The result shows up on the little revolution counter, and I will read it out to you all. Remember you all have an even chance because the small ones ride against smaller weights and the big ones against bigger weights. Now stand in a half circle so that you can all see every try as you wait your turn.

(3) *Second Trial.*—You are each given one more try. If this result is better than the last it will count as your score—so make up your mind to try harder and make that wheel go round still faster. Grip those handles tight and put everything you've got into it.

POSSIBLE FACTORS AFFECTING RESULTS.—At the very outset it was considered possible that certain individuals might be favoured in the tests due to some kind of specific experience.

In order to investigate these aspects thoroughly an assessment was made of each child's experience in using a bicycle or tricycle, in working with a wringer or mangle, in walking upstairs to flats four and five stories high, and in swimming. The results were carefully evaluated by assigning appropriate numbers for each grade of experience. It was found that none of these experiences had any perceptible relationship to the results of the tests.

TABLE II
HEIGHTS AND WEIGHTS

Sex	Boys				Girls			
Cities	London		Sydney		London		Sydney	
Groups	Height (cm.)	Weight (kg.)	Height (cm.)	Weight (kg.)	Height (cm.)	Weight (kg.)	Height (cm.)	Weight (k.g)
F	140	31·1	140	33·5	140	31·8	140	32·6
C	136	30·7	136	30·4	135	29·5	135	30·1
Mean	138	30·9	138	31·9	137	30·6	137	31·3
F+	143	34·0	143	33·8	—	—	—	—

COMPARISON OF RESULTS

Height and Weight

BOYS.—Surprisingly little difference was found in physical dimensions between boys from the two cities (Table II).

The agreement is within a centimetre in height in each of the pairs of schools selected—136 cm. for both C groups, 140 for both F groups, and 143 for the F+ groups.

The Sydney boys averaged about one kilogram heavier than the London boys; since this did not affect the main object of the research no analysis was made for statistical significance.

GIRLS.—Much the same relationships in body dimensions were found for the girls, heights being nearly identical in the corresponding C and F groups, and the Sydney girls being a little heavier (Table II).

Performance

In Figs 2 and 3, the mean performance for each group is calculated as a percentage of that for the best group. The results are then represented by a series of rectangles arranged in order, descending from the 100 mark. Each such rectangle is labelled by the symbols already explained—F++, F+, F, I, and C. The Sydney results are shown by the clear rectangles, the London results by the shaded rectangles. The research centres in the comparison of the F and C groups for London and Sydney, but the other results are included for further interest.

BOYS.—Fig. 2(*a*) establishes that in the case of the 10-year-old boys (arm test) the whole Sydney group is well in advance of the whole London group.

The F London group is about 25 per cent. lower than the F Sydney, and even the F++ London is about 20 per cent. lower than the F+ Sydney. The C London is about 10 degrees below the C Sydney.

In the leg test for boys (Fig. 2*b*), there is again a distinct superiority of F and F+ Sydney, as against F and F++ London, but the difference between the C groups is not significant.

When the results of the arm and leg tests are taken together* the F Sydney groups show a clear superiority over the F London groups (Fig. 2*c*).

* For calculation see Appendix B

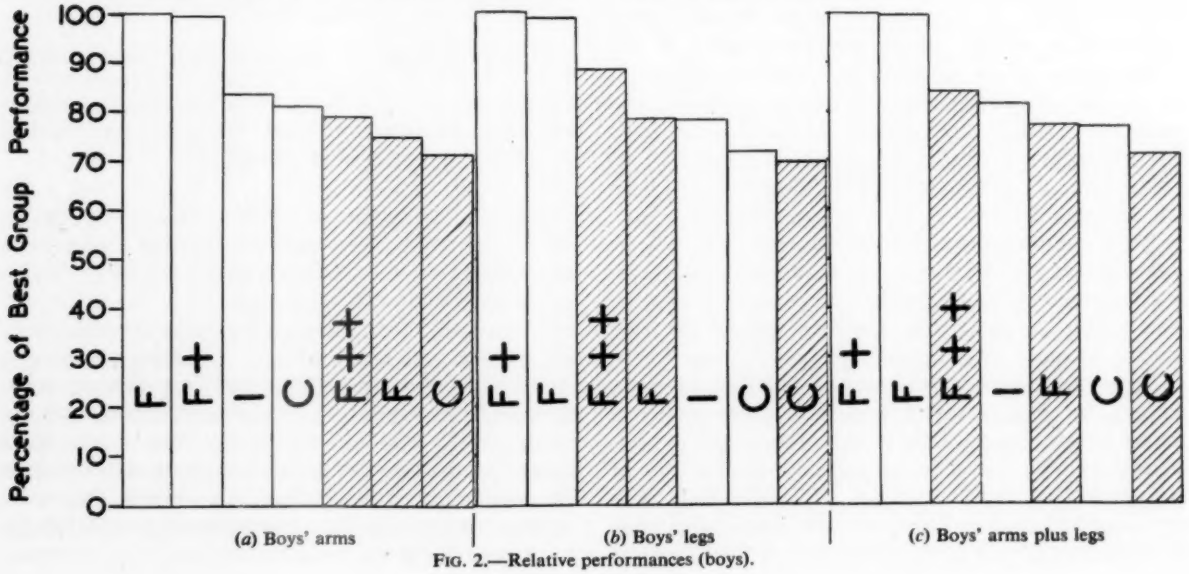


FIG. 2.—Relative performances (boys).

The combined results of the C groups were compared statistically, and it was found that the superiority of Sydney boys was established at the probability level 0·05, *i.e.* the odds against its occurrence by chance are 20 to 1.

GIRLS.—Fig 3 (*a*) shows that, in the arm test, as with the boys, the F Sydney groups are about 18 per cent. ahead of the F London group. Although C Sydney appears to be somewhat ahead of C London (5 per cent.) it was necessary to investigate the results statistically, and this showed that the superiority is not so well established, being only about 7 to 1 in favour.

Fig. 3 (*b*) also, as in the case of the boys, shows a considerable superiority in the leg test of F Sydney above F London—a little more than 12 per cent., but the small graphical superiority of C Sydney over C London is not significant.

Consequently, when the arm and leg tests are considered together (Fig. 3*c*) for an overall comparison of work capacity, although the F Sydney group shows a considerable superiority over F London, the C groups are not significantly different.

COMPARISON OF THE F AND C GROUPS.—As may well be expected, both in London and in Sydney the F groups performed much better than the C groups and this superiority was maintained throughout all the tests for both boys and girls.

A reference to the preceding figures shows no exception to this general result. A further fact stands out in these graphs, namely that the superiority of F over C is much more marked for Sydney than for London.

A more detailed analysis of the results was undertaken to discover how this rather challenging phenomenon comes about. Each set of results, for boys and girls in London and Sydney, was divided into standard deciles and each decile for London was compared with its fellow for Sydney (Figs 4 and 5, overleaf).

The remarkable appearance is presented that not only are the means for the top deciles (Sydney and London) farther apart than those for the bottom deciles, but that a reasonably regular gradation is shown in the intermediate deciles.

The Figures all show similar converging lines, but the convergence is not equally distinct in all cases. A further examination was therefore made of the terminal deciles as an overall test of the tendency for convergence; the mean value was calculated for each terminal decile taken as a whole, and the results assembled in Table III (overleaf).

In the arm test the Sydney/London ratio is substantially higher in the top decile than in the bottom decile for both boys and girls, and the overall convergence is very marked. This convergence is also seen for both boys and girls in the leg test, where the superiority of the Sydney children is marked in the top decile but negative in the bottom decile.

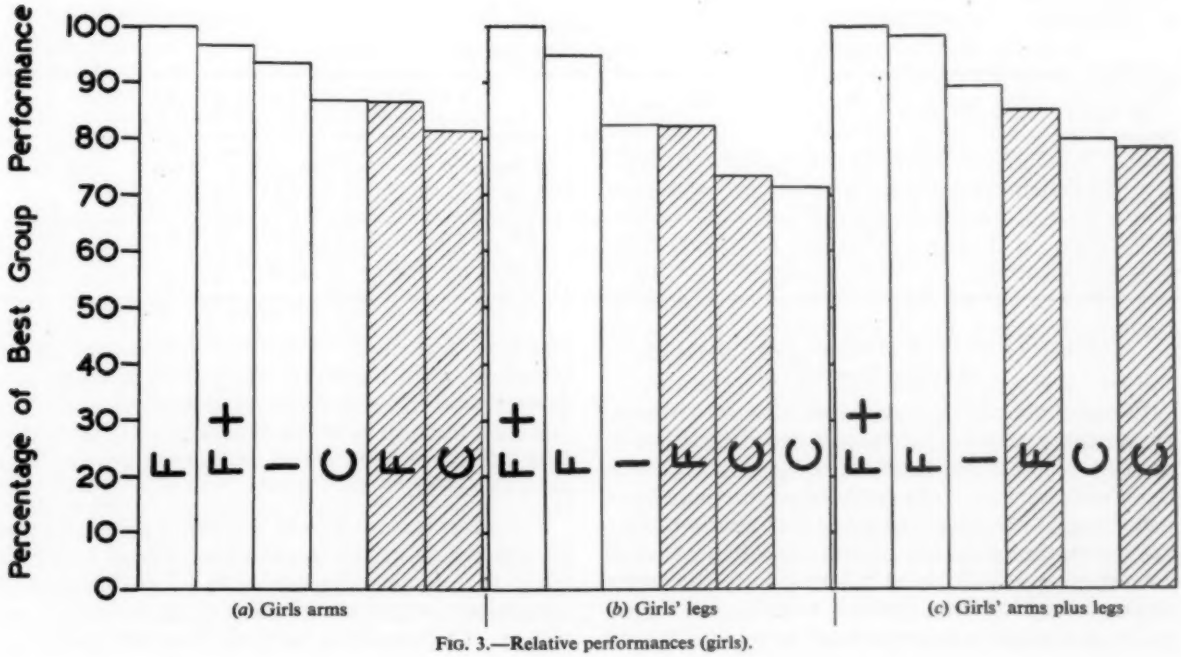
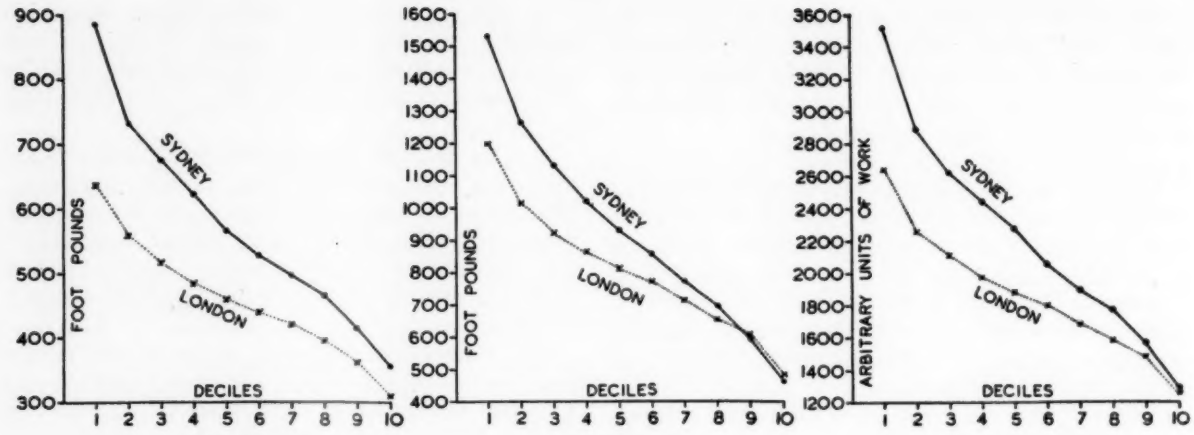
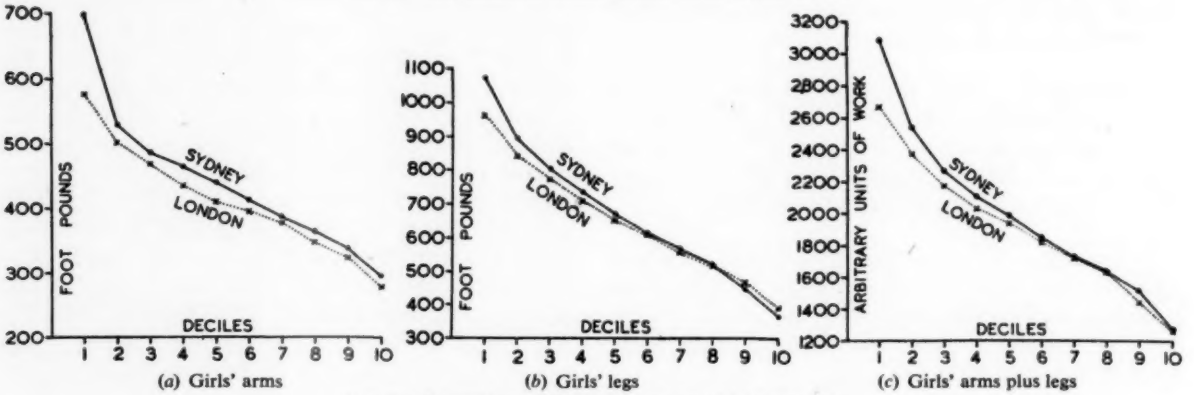


FIG. 3.—Relative performances (girls).



(*a*) Boys' arms (*b*) Boys' legs (*c*) Boys' arms plus legs

FIG. 4.—Comparison of deciles of London and Sydney boys.



(*a*) Girls' arms (*b*) Girls' legs (*c*) Girls' arms plus legs

FIG. 5.—Comparison of deciles of London and Sydney girls.

TABLE III

MEAN VALUES IN FOOT POUNDS FOR DECILES LISTED

Test	Arm				Leg			
Sex..	Boys		Girls		Boys		Girls	
Decile	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
London	638	309	576	279	1,197	483	963	391
Sydney	886	356	699	296	1,531	465	1,072	364
Ratio: Sydney/London	1·39	1·15	1·21	1·06	1·28	0·96	1·11	0·93

ANALYSIS OF THE RELATION OF PERFORMANCE TO BODY-WEIGHT

Previous experience has shown that in a variety of athletic performances the absolute result is frequently a linear function of body-weight over a fairly wide range, *e.g.* in a cycling race the competitors may range in weight from about 120 to nearly 180 lb., yet neither the lighter nor the heavier men have much advantage in hill climbing, where clearly the major work consists in lifting the body-weight. The lighter cyclist has a lighter cycle and this helps to maintain equality. Moreover, in an extensive experience of laboratory tests over hundreds of cases, in which each subject worked on the bicycle ergometer against a standard fraction of his body-weight as load, it was found that neither the lighter nor the heavier men were favoured.

For this reason it was considered that in the limited weight range in question it would be worth while to calculate the constants for each group to determine the regression line of performance on weight. This was done for both boys and girls.

The graph for boys is shown in Fig. 6; that for girls is similar in shape but the differences in slope are less marked. A statistical investigation of the reality of the difference in the regression lines, considering boys as one group and girls as another, shows that the difference is real at the probability level 0·000001. This means that it is about a million to one in favour of the reality of the difference.

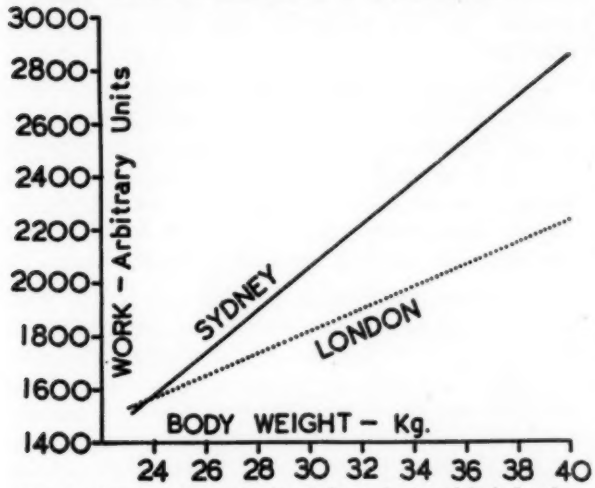


FIG. 6.—Boys' work capacity in relation to body-weight in London and Sydney.

Since each pair of graphs shows a point of intersection, the principle mentioned above that performance (*P*) is apt to be a linear function of weight (*W*) was applied by calculating the ratio *P*/*W* at this point. It was then calculated whether this ratio was maintained at the higher weight levels (Table IV).

TABLE IV

RELATION OF PERFORMANCE TO WEIGHT *P*/*W* IN ARBITRARY UNITS

Sex	Boys		Girls		Boys + Girls	
Weight Group	Lighter at 24 lb.	Heavier at 40 lb.	Lighter at 24 lb.	Heavier at 40 lb.	Lighter at 24 lb.	Heavier at 40 lb.
London	66	56	64	61	65	58+
Sydney	66	71	64	65	65	68

The following facts are demonstrated by Table IV:

(1) There is little difference between the work capacity of the small boys and the small girls in relation to their weight in either London or Sydney.

(2) As weight increases in the London children there is a decided falling off of work capacity in relation to body-weight, the difference being more marked in the boys than in the girls.

(3) As weight increases in the Sydney children there is no falling off of work capacity in relation to body-weight but rather a slight increase; this increase is quite marked in the boys but not significant in the girls.

In commenting on the terminal deciles above, it was pointed out that the relative performances—London/Sydney—were not very different in the lowest decile, but that Sydney showed marked superiority in the top decile. It may be asked whether this phenomenon has any relation to the trend of the *P*/*W* ratio with increase of body-weight—the ratio being much the same in both cities in smaller children, but markedly superior in Sydney in larger children.

The underlying common factor may well be that most of the lighter children come from the C groups and most of the heavier ones from the F groups; it has already been shown that F Sydney scores well above F London.

The question naturally arises whether the difference in the food position in the two countries is in any way concerned. The writer was very struck by the remarkable organization obtaining throughout the London schools whereby hot midday meals are made available for the children, together with regular supplies of milk.

If the apparent superiority in some respects of the C London over the C Sydney children is real, it may be related to the question of food, since in Sydney there is no such provision for meals although the milk position is much the same. Food neglect in children may have been remedied in London to a better degree than in Sydney.

The falling off of performance in the heavier London children may be due to the fact that bigger children require more food, and it may be worth inquiring whether this additional requirement is generally available to these bigger children.

The writer well recalls that, when he was present at the Helsinki Olympic Games in 1952 as Scientific Adviser to the Australian team, there were many discussions on food among the athletes from various countries. He gained the impression that the British athletes as a group were convinced that they were handicapped in comparison with those from other countries (especially America and Australia), in that they appeared to be typically "protein hungry" because, as they claimed, of the limited availability of meat in Britain.

Another fact to remember is that the children tested in London were born during the war years. This could hardly account for all the phenomena discussed above, but might have some undetermined bearing on the general result.

Another factor which merits consideration is a possible difference in motivation between the two groups of children. It has been suggested that "Australians are deviating toward the American way of life in which desire to be best in everything

motivates both children and adults". There may be some truth in this idea, though I cannot recall any facts in my experience which would support it for adult athletes—let alone children. I must confess that to begin with I wondered whether an Australian experimenter could gain the confidence of the English children as easily as that of Australian children, and whether he would be able to inspire the former to try their hardest. From the first English group onwards, however, my fears were dispelled, and I was deeply impressed by the children's determination, real eagerness to excel being the keynote of their attitude. The detailed analysis of the relation of performance to body-weight, which is the basis of the main differences between the London and Sydney groups, leaves little scope for any appreciable difference in motivation.

Summary

(1) A new type of ergometer is described which automatically readjusts any tendency to variation in load so that the load is maintained constant throughout the experiment.

(2) The ergometer is simple of construction and easily transported, and can be readily used for laboratory tests on groups of subjects in widely different places.

(3) A comparative study was undertaken to apply tests for work capacity to different classes of children in London and corresponding groups in Sydney.

(4) In both cities sample schools were selected to compare children living in the more congested areas (C) with those living under more favourable conditions (F). The study was limited to 10-year-old children in order to secure sufficient numbers for comparison. In each city the number tested exceeded three hundred.

(5) The work capacity of the major muscle groups below the waist and of similar groups above the waist was tested.

(6) An investigation was made of factors in a child's experience which might influence individual results; it was established that such differences are relatively small and did not influence the London/Sydney comparisons.

(7) Little difference was found in the heights and weights of the 10-year-old children in comparable schools in the two cities.

(8) In both cities the heights and weights of the F children were substantially above those of the C children, and the F groups accomplished much more work than the C groups.

(9) When the results of the two tests are combined for all round comparison the F Sydney groups were found to be well ahead of the F London groups. In the boys this superiority was over 20 per cent. and in the girls about 13 per cent. All the C Sydney groups appeared a little superior to the C London groups, but this difference was too small to be significant.

(10) Analysis of the extreme deciles in the four groups, London and Sydney, boys and girls, showed a clear superiority of Sydney above London for the top decile in each, but little difference if any in the bottom deciles. In the leg test, bottom decile, Sydney appeared slightly inferior to London, but the difference was not statistically significant.

(11) When the results for the two cities were compared by considering the ratio of performance to body-weight it was found that the lighter children, both boys and girls, in Sydney were no better than, and possibly inferior to, those in London. As the weight of the child increased, however, the superiority of the Sydney groups over the London groups became more marked.

The facts established in (10) and (11) above pose a problem. Why should the heavier children in Sydney—both boys and girls—work at higher rates in the tests than their counterparts in London, while the lighter ones do not? One explanation could be that the ratio of muscle to fat is greater in the heavier Sydney groups than in the heavier London groups. It may be asked whether the fact that protein food is more freely available in Sydney than in London has any bearing on the finding.

My thanks are due to the Ministries of Education in England and New South Wales for valuable help so freely given, and to the headmasters and headmistresses of the schools visited for their uniformly friendly co-operation and help, to the Blue Star Line Shipping Company who generously conveyed all the apparatus to London and back, Messrs. K. Smith and B. McGee who assisted with the work at the Sydney schools and in the subsequent routine statistical calculations, Dr. —. Lancaster of the Department of Public Health and Tropical Medicine, who was responsible for the statistical evaluation of the difference in the regression lines of performance on weight, and to Messrs. Woodward-Smith and K. Clifford of the Department of Illustration for preparing the figures.

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APPENDIX A

The principle of the new ergometer (Fig. 7) depends on dividing the friction band into two parts, that connected to the lighter weight (freely suspended at rest) having a greater coefficient of friction (C.F.) than that connected to the heavier weight.

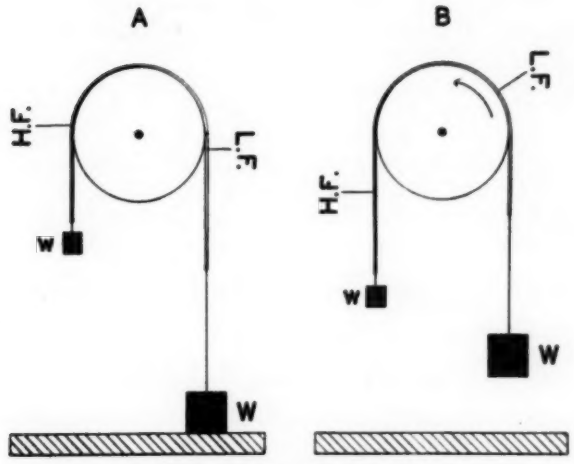

FIG. 7.—Principle of action of the new ergometer.

W. Relatively large weight compared with a smaller *w*.
H.F. That part of the friction band with a higher coefficient of friction
L.F. That part of the friction band with a lower coefficient.
(*A*) At rest (W resting on floor).
(*B*) Wheel revolving in direction indicated by arrow.

When the wheel is rotated (provided that the ratio W/w lies within a certain range) sufficient friction is available to lift W. As this is lifted the total friction operating on the rim of the wheel steadily decreases until it reaches the value $(W - w)$ when the system comes to equilibrium. If any subsequent variation of total friction occurs, the band automatically moves in a direction to compensate for it; if the friction increases the band moves so as to reduce friction and *vice versa*. An automatic self-adjusting system is thus obtained and any pre-arranged load which may be set to begin with will be maintained at at constant value. In general a suitable weight carrier is attached to each end of the band, the weights of the empty carriers being such that in motion the junction point of the two portions of the band moves about 45° on the wheel. This gives a convenient position of equilibrium, so that any subsequent migration of this junction point sets in motion substantial adjusting forces. Any predetermined degree of friction or total load may be increased by placing a heavier weight in the larger carrier and a lighter one in the smaller carrier, keeping the ratio of the added weights the same as the ratio of the weights of the carriers.

Preliminary tests showed that the device worked well, but it was not easy to make any given system of band plus weights cover a wide range of resistances.

It was difficult to find materials suitable for such a double band with sufficiently different Cs.F., for after continual use the band with the higher C.F. became smoother so that the C.F. decreased and might not suffice to raise the larger weight from the floor.

A given composite band gave satisfactory service for several months' work involving tens of thousands of revolutions, but finally developed irregularities and had to be discarded.

Various changes were made in the system during a period of nearly 4 years. The pairs of materials tried for the double band are set out below:

COEFFICIENT OF FRICTION

Higher	*Lower*
Cotton webbing	Thin flexible wire in groove on rim
Rubber	Cotton webbing
Rubber	Steel band
Cork-faced cotton band	Steel band
Leather	Cotton webbing
Leather	Steel band
Brake lining (asbestos)	Cotton webbing
Brake lining (asbestos)	Steel band

As it would appear advisable, at first sight, to secure a high ratio between the Cs.F. of the two parts of the band, the combination of rubber and steel gave better results than other combinations, since this gives a ratio of 6 or 7 to one, while most of the other combinations give ratios of about 3 or 4 to one. Two difficulties arose, however, when such a band had been in use for several months:

(*a*) When the machine had been left unused for 10 days or so, the rubber seemed to "stick" so that it started up with a jerk, and the band flew off.

(*b*) Such a high ratio is apt to produce abrupt changes in resistance with relatively minor changes of position and this may lead to troublesome oscillation.

The combination of cork-faced fabric and steel also yields a high ratio (about 6 to 1) but the cork has behaved much more constantly than the rubber and the two ergometers have been running with this combination for years without breakdown.

Another difficulty sometimes arises in that the system does not continue to balance indefinitely

with increase in the absolute values of W and w even though the ratio of W and w is kept constant. Thus the system may balance well with weights of say 8 and 2 lb. with a W/w ratio of 4, and yet with heavier weights of 16 and 4 lb. with the same ratio the large weight may not be lifted from the floor when the wheel starts revolving, or after being lifted may sink slowly back again. Adjustment may quickly be made by adding equal weights to the carriers on each side, so that while $W - w$ is kept the same, the ratio W/w is slightly reduced and W is lifted into free equilibrium again.

A further improvement was made by using steel for the band with the lower C.F. and canvas for the band with the higher C.F. A small pot of oil was arranged with a wick to touch the rim of the wheel and provide a film of oil. The effect was to decrease the friction of the metal with little or no decrease in the friction of the canvas. In some cases it would appear that the friction of the canvas was even slightly increased. The difference between the two coefficients of friction was thus widened to the fullest extent. This device has been in continual use for about 4 years.

APPENDIX B

It was thought advisable to make some general comparisons combining the results of the separate tests for arms and legs (Figs. 2*c*, 3*c*, 4*c*, 5*c*).

Equal weight was given to each test by the following procedure:

(1) All the corresponding results for London and Sydney were pooled, and the mean values were calculated. This yielded four mean values:

boys' arms boys' legs girls' arms girls' legs.

(2) If the absolute performance of a given child for the leg test be L_x, and the mean for London plus Sydney L_m, the relative performance was calculated as $\frac{1000\,L_x}{L_m}$, the arbitrary factor 1000 being used to clear decimals.

The same child's arm test was also calculated as a relative performance by using the expression $\frac{1000\,A_x}{A_m}$.

These expressions enabled his combined performance (arms plus legs) to be assessed as $\frac{1000\,L_x}{L_m} + \frac{1000\,A_x}{A_m}$.

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OXFORD CHILD HEALTH SURVEY
EFFECT OF CHILDISH AILMENTS ON SKELETAL DEVELOPMENT*

BY

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One of the main objectives of the Oxford Child Health Survey was to study the effects of environment on physical development (Ryle, 1948), and of the two dozen papers which have so far appeared six have dealt with this topic (Hewitt and Stewart, 1952; Acheson, 1952; Stewart and Westropp, 1953; Westropp, 1953; Acheson and Hewitt, 1954a, b; Acheson and Jefferson, 1954). The form that these studies have taken has varied considerably, since methods which are able to detect continuous influences cannot always be applied to the study of influences which operate for short periods or intermittently. In one of the earlier studies measurements of standing height and skeletal maturity at various ages were correlated with economic conditions (Acheson and Hewitt, 1954a). This relatively simple treatment of the data was justified because the number of children whose social background (as judged by the father's occupation) changed during the survey was negligible. Therefore the total measurements, which represented life increments of growth (*i.e.* height) and development (*i.e.* skeletal maturity) were appropriate to the analysis. That is to say, the study was focussed on a continuous influence which it was reasonable to suppose would be reflected in increases of certain types of body measurement.

On this occasion height and skeletal maturity are again used as indices of growth and maturation, but the influence which we propose to study, namely childhood illness, operated intermittently. The analyses are therefore conducted in terms, not of life increments, but of annual increments. It follows that the units of study will not be individual children —of whom there were 650—but *child-years*. The total child-years in the survey was 5 × 650 (3,250), but only 2,296 could be used in this study (Table I). The reason for this reduction is that annual increments could be obtained only for children who had been examined both at the beginning and end of a year. Since none of the relevant observations were made at birth the whole of the first year of life is automatically excluded.

TABLE I

NUMBER OF CHILDREN EXAMINED AT THE BEGINNING AND END OF EACH YEAR OF LIFE

Year	Boys	Girls	Total
Second	327	322	649
Third	301	295	596
Fourth	273	271	644
Fifth	254	253	507
Total No. of Child-years ..	1,155	1,141	2,296
No. of Individual Children ..	327	323	650

MATERIAL

A general account of the organization of the survey and the information collected has been given by Stewart and Russell (1952). The following data were assembled for the second, third, fourth, and fifth years of life:

(1) STANDING HEIGHT INCREMENTS.—For the third, fourth, and fifth years of life the difference was determined, in half-inch units, between the standing height at the beginning and end of each 12-month period. Since few of the children could stand at the age of 1 year the increment for the second year of life was taken as the difference between the leg length plus crown-rump length at 1 year and the standing height at 2 years (see footnote to Table II). There is, in fact, an appreciable difference between these two assessments of body length, but the error thus introduced should not bias the results since it is randomly distributed with respect to other variables studied.

(2) ILLNESSES (other than head colds).—Recruits to the Oxford Child Health Survey were all supposedly normal, healthy children, and though there were plentiful examples of acute illness the debilitating, chronic illnesses were not represented. On the basis of their annual sickness records, the children representing each year of life

* Material on which this paper is based was presented in part to the Association of Physicians of Great Britain and Ireland in Manchester on May 28, 1955 (Stewart and Acheson, 1955).

were allocated to one or more of eleven diagnostic groups, of which five were sufficiently large to justify separate analysis:

A. *Exanthemata* (mainly measles and chicken pox, also mumps, rubella, and scarlet fever).
B. *Lower Respiratory Infections* (only bronchitis, pertussis, and pneumonia).
C. *Upper Respiratory Infections* (mainly tonsillitis and otitis media, also mastoiditis and laryngitis).
D. *Skin Diseases* (mainly eczema and urticaria, also impetigo, scabies, etc.).
E. *Other Infections* (mainly intestinal, but also all other infections except head colds not included above).

If, in a given year, a child experienced several dissimilar illnesses, it appeared in each of the relevant diagnostic groups, but was never counted more than once in any individual calculation. In addition to the diagnostic grouping an arbitrary classification was made of the year's illness experience as a whole to distinguish children who had one or more "severe" illnesses from those whose illnesses were all "slight", or who had no illness at all (apart from head colds) during the year.

(3) Radiological Striation of Long Bones (Harris's Lines).—The *x*-ray material included films of right and left hands and knees, and records were kept of films revealing—either in the distal end of the femur, radius, and ulna, or in the proximal end of the tibia—the transverse striations originally associated arrest of growth by Stettner (1921a, b) but known in Great Britain as Harris's lines* (Harris, 1926, 1933). The cases in which Harris's lines had been recorded in both knee films were then reviewed; if the lines traversed the whole width of the bones they were classified as "complete", if not as "partial". (Complete lines in knee films were almost always accompanied by similar lines in radius films, Figure, opposite). An examination of successive knee films made it possible to identify the child-years during which new Harris's lines had appeared. Sometimes more than one new line appeared in the course of the same child-year, but such years were still classified in the "partial" group unless at least one line was "complete".

(4) Skeletal Maturity Increments.—A method recently described (Acheson, 1954) for assessing skeletal maturity in "Oxford Units" was applied to the *x*-ray films of the hands and knees. By keeping separate scores for the carpus, the epiphyses of the long bones of the hand and wrist, and the knee, three assessments of skeletal maturity were made at half-yearly intervals from 6 months to 5 years.* From these assessments, three sets of annual increments were obtained by calculating differences in the scores at the beginning and end of each year.

*Harris (1926) suggested that the lines were caused by a temporary arrest of the growth of the epiphyseal cartilage; this view has been borne out by the researches of Follis and Park (Park, 1954).

Methods of Analysis

From the assembled data, the following basic figures were calculated for boys and girls separately and for each successive year:

(*i*) Means and standard deviations of height increments (Table II);

(*ii*) Means and standard deviations of skeletal maturity increments for three sets of bones (Table III);

(*iii*) Children (with corresponding standard deviations) exhibiting new Harris's lines (Table IV).

Table II
AVERAGE HEIGHT INCREMENTS (INCHES) BY SEX AND YEAR OF LIFE

Year	Boys		Girls	
	Mean	S.D.	Mean	S.D.
Second* ..	3·25	1·27	3·26	1·15
Third	3·42	·80	3·65	·80
Fourth	2·85	·61	2·93	·60
Fifth	2·58	·53	2·63	·51

*Mean increment artificially low and standard deviation artificially high because leg length plus crown-rump length was used in place of standing height at 12 months (see text).

Table IV
INCIDENCE OF "COMPLETE" HARRIS'S LINES BY SEX AND YEAR OF LIFE

Year	Boys		Girls	
	Proportion	S.D.	Proportion	S.D.
Second	·1103	·3135	·1718	·3772
Third ..	·1833	·3869	·2519	·4340
Fourth	·3360	·4723	·3305	·4704
Fifth ..	·3377	·4730	·2895	·4525

*When this method was first described it was suggested that the units awarded to epiphyses of the long bones of the hand should be scaled down in such a way that the total scores for the three areas bore a linear relationship to age. No such scaling has been adopted here. See Discussion below.

Table III
AVERAGE SKELETAL MATURITY INCREMENT (IN OXFORD UNITS) BY SEX AND YEAR OF LIFE

Year	Carpus				Epiphyses							
					Hand and Wrist				Knees			
	Boys		Girls		Boys		Girls		Boys		Girls	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Second	2·41	1·67	2·85	2·17	7·73	2·46	9·45	2·53	2·35	1·62	2·92	1·58
Third	2·58	2·32	4·20	3·78	5·72	2·22	3·48	2·52	2·63	1·71	3·88	1·85
Fourth	4·32	2·66	7·51	3·59	2·21	1·90	·87	1·10	2·59	1·62	4·11	2·20
Fifth	4·98	2·64	7·70	2·37	·63	1·33	·67	1·08	2·97	1·71	3·05	1·97

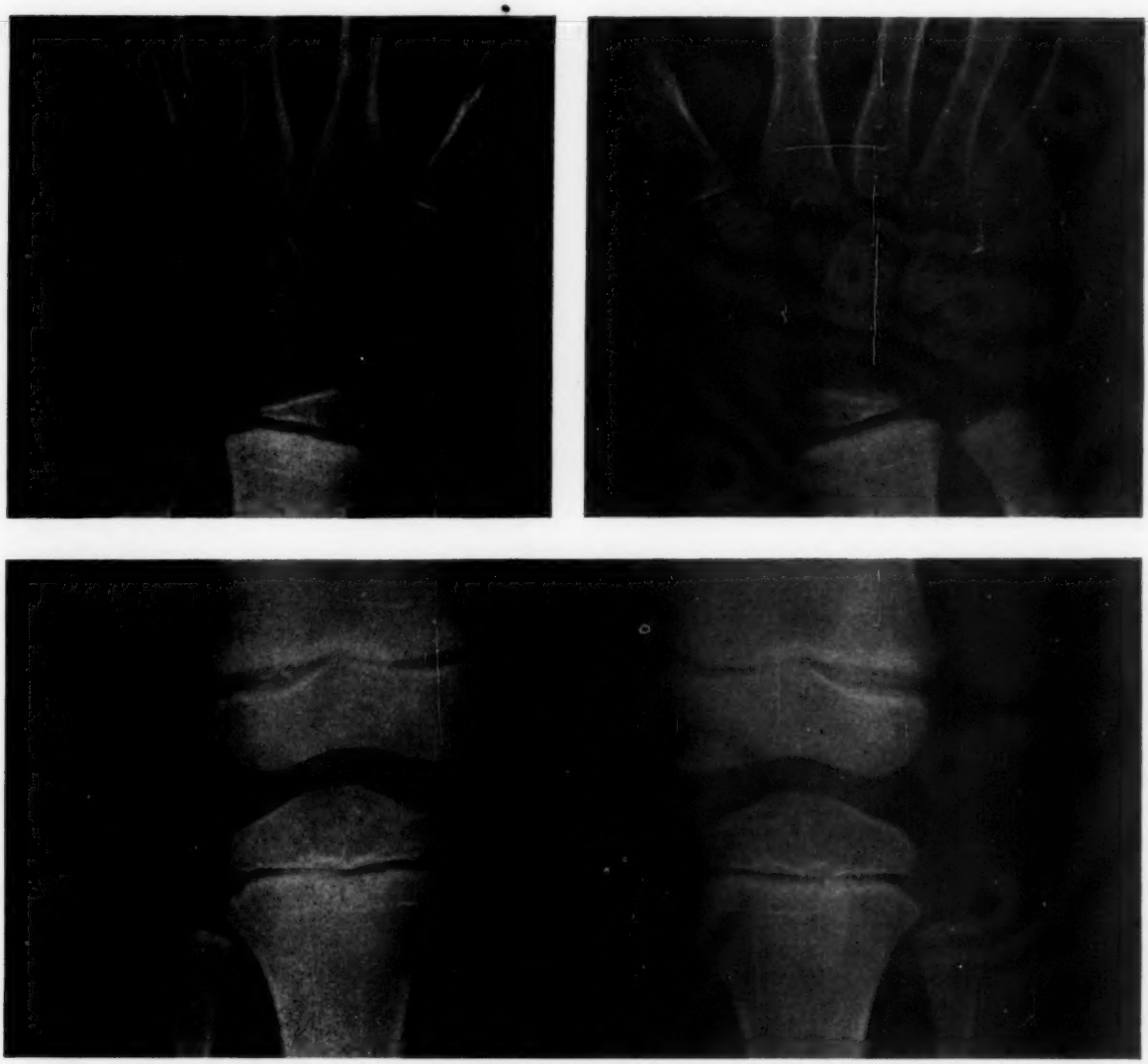

Figure.—Wrists and knees of a boy aged 5 years, showing transverse marking on each radius, femur, and tibia, and also on the right fibula. This child had suffered a severe attack of measles with bronchitis 9 months previously. The distance of the lines from the epiphyseal cartilage shows the amount of growth which has occurred since his illness.

Tables were then prepared to correlate six pairs of four variables, *viz.*:

(1) Illness with height increments,

(2) Illness with skeletal maturity increments,

(3) Illness with Harris's lines,

(4) Harris's lines with height increments,

(5) Harris's lines with skeletal maturity increments,

(6) Height increments with skeletal maturity increments (see final section of this paper).

For Pairs (1) to (5) of the above list the statistical analysis followed this pattern:

The group of child-years belonging to a given sex and year of life (*e.g.* boys aged between 12 and 24 months) was divided into sub-groups defined in terms of the first member of the pair (*e.g.* nil, slight, and severe illness experience) and mean values were calculated for each sub-group of the second member of the pair (*e.g.* mean height increments). In order that a direct comparison could be made between the effect of illness on skeletal maturation, on growth and on bone striation in any year, it was essential that these three processes were measured in comparable units. Therefore the mean of each sub-group was then compared with the mean for the whole group, and departures from the general mean were expressed in units of the appropriate standard deviation. This process was repeated seven times for the remaining sex and year of life groups. Finally all eight sets of differences were combined in a weighted average.

For example, the numbers of boys whose illness experience during the second year of life were rated as

nil, slight, and severe, were 69, 135, and 51 respectively. Mean height increments of these sub-groups were:

nil 3·41″;
slight 3·25″;
severe 3·04″.

These means differed from the general mean of 3·25″ (see Table II) by +·16″, ·00″, and −·21″; expressed in standard deviation units these differences become +·13, ·00, and −·16.

When the same process had been followed eight times the weighted average differences were found to be:

nil +·12 (549 child-years)
slight −·02 (1,205 child-years)
severe −·20 (223 child-years).

In the calculations three-figure accuracy was preserved, but only the first two figures are shown in the Tables where it has also been found convenient to multiply each figure by one hundred (*i.e.* each standard unit (S.U.) equals 1 per cent. of a standard deviation).

Results

The results obtained from the first three tabulations listed above, which incorporate observations from the years of one to five, are summarized in Table V. In the first three lines of Table V the illnesses for approximately 2,000 child-years are classified on a severity basis in order to compare development during years with no illness other than head colds (28 per cent. of the total) with that achieved during years when there was slight illness (61 per cent.) or severe illness (11 per cent.). The lower part of Table V distinguishes five diagnostic groups in order to compare the effect on development of different types of illness.

TABLE V

DEVIATION (IN S.U.s) FROM AVERAGE HEIGHT INCREMENT, AVERAGE SKELETAL MATURITY INCREMENT, AND AVERAGE INCIDENCE OF COMPLETE HARRIS'S LINES, ASSOCIATED WITH HISTORY OF ILLNESS DURING THE YEAR
SEXES COMBINED, AGES ONE TO FIVE YEARS

Illness Group		Body Length Increment	Skeletal Maturity Increment	Complete Harris's Lines
Severity	Nil ..	+12	+2	−21
	Slight ..	− 2	−0	+ 1
	Severe ..	−20	−3	+43
Diagnosis	A* ..	− 6	+1	+25
	B ..	− 3	−5	+28
	C ..*	− 7	+1	+ 1
	D ..	−10	+2	+ 8
	E ..	− 2	−4	+13

*See text.

No one of the diagnostic groups seemed to affect growth much more or less than any other, but the severity groups were found to have significantly different height increments (from analysis of variance, $P < ·001$). The effect of slight illnesses was to reduce contemporary height increment by 14 S.U.s (= 12 + 2), while severe illnesses brought about a reduction of 32 S.U.s (= 12 + 20). Similar findings were established for the two sexes separately, though the growth of boys appeared to be affected slightly more than that of girls. Thus the difference between the nil illness group and the combined slight and severe illness groups was + 19 S.U.s for boys ($P < ·02$) and + 15 S.U.s for girls ($P < ·05$). Corresponding differences for the sexes combined were:

Year	*S.U.s*
Second	+17
Third	+18
Fourth	+17
Fifth	+16

These findings imply that any children who escaped all illness between the ages of 1 and 5 would at the end of that period have been, on average, 1″ taller than those who experienced a "severe" illness in each of these years, and 0·4″ taller than those who had the average amount of illness. In fact, relatively short periods of sickness alternated with relatively long periods of good health, and it may be that the latter gave most children an opportunity to retrieve the ground that had been lost through illness. The present study, however, provides no positive evidence that such periods of compensation did occur. Thus the mean deviation from average height increment for 186 child-years immediately following years with severe illnesses was only + 8 S.U.s, which is less than half the negative deviation for years in which a severe illness occurred and does not differ significantly from zero. (Any compensatory spurt which occurred during the same 12-month period as an illness is, of course, already allowed for in the estimates shown in Table V.)

According to the second column of Table V differences between skeletal maturity increments for various illness groups were much smaller than corresponding differences in body length increments, and were not statistically significant. Thus the nil illness group gained only 5 S.U.s more, on average, than the severe illness group. As in the case of body length, boys appeared to be affected slightly more than girls, the mean difference between nil and other illness groups being + 3 S.U.s for boys and + 1 S.U. for girls. Even these trivial differences may exaggerate the effect of illness on skeletal maturation as a whole. For, although Table VI shows that there was a suggestive relationship between health and maturation of the *carpal bones*, the development of the *epiphyses of long bones* evidently bore no relation to the illness histories. According to Todd (1932, 1933), development of the carpal bones tends to be

retarded by minor stresses, which makes these bones, in his view, less reliable as maturity indicators than the long bones of the hand and forearm. Neither Todd nor his associates have published evidence in support of this statement, but the present findings suggest that he may have been right.

TABLE VI

DEVIATION (IN S.U.s) FROM AVERAGE SKELETAL MATURITY INCREMENT ASSOCIATED WITH HISTORY OF ILLNESS

History	Carpus	Hand and Wrist	Knee
Nil	+ 4	+1	+1
Slight	+ 0	−1	−1
Severe	−12	+2	+2

The observation that illness failed to cause a delay in skeletal maturation commensurate with the interruption of longitudinal growth probably means that it will have an effect on final adult height. For it implies that during periods of ill-health the children advanced almost, if not quite, as far towards the stage at which their epiphyses would close and growth will cease as if they had always remained well and had grown in stature at their usual, healthy, rate.

The last column of Table V relates to the incidence of new, complete Harris's lines. Measured in S.U.s, variations associated with illness were much greater than variations in growth and maturation, the frequency of new lines being raised by 22 S.U.s (= 21 + 1) in the slight illness group and 64 S.U.s (= 21 + 43) in the severe illness group. These differences, which are highly significant ($P < \cdot 001$), confirm the views expressed by Stettner (1921a, b), Harris (1926), and Todd (1932) that illnesses which occur during the period of growth tend to produce these lines. In the present survey lower respiratory infections and exanthemata (particularly measles) stood out as diseases particularly likely to produce bony striation. Though the absolute frequency of Harris's lines was greater among boys than girls, their association with recorded illnesses was more clearly seen in girls. Thus the difference between the nil and the other illness groups was + 21 S.U.s for boys and + 36 S.U.s for girls, a difference which approaches statistical significance.

Though the association between Harris's lines and illness was strong, it was far from being a one-to-one correspondence. Several apparently severe illnesses had left no trace on the bones, and in several films heavy lines were seen when no illness had been recorded. Since Harris's lines cannot be distinguished until healthy bone has developed between them and the epiphyseal cartilage, it was possible that a number of the illnesses recorded occurred towards the end of a child-year and produced bony changes which did not appear until after the next *x*-ray had been taken. However, even when such cases were taken into account, there remained a substantial residue of "unexplained" lines.

This finding led us to compare the height and skeletal maturity increments achieved during years when Harris's lines had or had not appeared (regardless of whether they were associated with illness). This required an analysis of the fourth and fifth tabulations listed above, the results of which are summarized in Table VII. As in Table V there was a highly significant variation in height increment ($P < \cdot 001$ for both sexes combined and for boys alone; $P < \cdot 20$ for girls alone) and a much smaller, non-significant variation in skeletal maturity increments (only the result relating to *carpal* maturation in boys reached the conventional 5 per cent. level of significance).

TABLE VII

DEVIATION (IN S.U.s) FROM AVERAGE HEIGHT AND SKELETAL MATURITY INCREMENTS ASSOCIATED WITH APPEARANCE OF HARRIS'S LINES

Harris's Lines	Body Length Increment			Skeletal Maturity Increment (Average of 3 Areas)		
	Both Sexes	Boys	Girls	Both Sexes	Boys	Girls
Nil ..	+ 9	+17	+3	+3	+2	+3
Partial	+ 1	−1	+3	−1	+1	−4
Complete	−15	−21	−8	−2	−4	+0

To carry the analysis one stage further the material was so arranged that for each year of life the following combinations were identified:*

(*i*) severe illness and complete Harris's line,
(*ii*) severe illness but no Harris's line,
(*iii*) no illness but complete Harris's line,
(*iv*) no illness and no Harris's line.

This arrangement showed that the height increments had been more seriously affected when severe illness was associated with a complete Harris's line than when an illness or line was recorded alone (Table VIII, overleaf).

Once again, there was more disturbance of height increments than of skeletal maturity increments, the range of variation in the former (44 S.U.s) being nearly four times as great as in the latter (12 S.U.s).

*The arbitrary division of the material into 12-month periods may also have affected estimates of the effect of illness on growth and skeletal maturation, but in these cases there is no reason to expect either an upward or a downward bias in the apparent correlations, and in particular the relative magnitude of the correlations should not be affected.

TABLE VIII

DEVIATION (IN S.U.s) FROM AVERAGE HEIGHT AND SKELETAL MATURITY INCREMENTS IN CERTAIN SELECTED GROUPS OF CHILD-YEARS

Increment	Illness Experience			
	Nil		Severe	
	Harris's Lines		Harris's Lines	
	Nil	Complete	Nil	Complete
Height	+18	+9	−3	−26
Skeletal Maturity*	+ 4	−3	−4	−8

*Average for carpus and epiphyses of hand and knees

One pair of variables remains to be considered, height increment and skeletal maturity increment. One attempt has already been made (Acheson and Hewitt, 1954a) to measure the relationship between rate of growth and rate of skeletal maturation as assessed by the standards of Todd (1937). From this we concluded that children who are precocious in skeletal maturation tend to be tall for their age, but are appreciably shorter than older children of equal skeletal maturity. The present assessments of skeletal maturity, together with annual increments in place of life increments, provides an opportunity to study the normal relationship between growth and maturation in slightly greater detail. The results are summarized in Table IX, in which findings for the sexes and years of life are kept separate. Where possible the analysis was conducted in terms of product-moment correlation, but when the distribution of maturity increments made this impossible the children were divided into groups on the basis of maturity increment, and mean height increments calculated for each group. For the sake of conciseness Table IX shows only the sign of the association found for each sex and year of life, together with an indication of statistical significance.

TABLE IX

ASSOCIATION BETWEEN HEIGHT AND SKELETAL MATURITY INCREMENTS

Year of Life	Carpus		Epiphyses			
			Hand and Wrist		Knee	
	Boys	Girls	Boys	Girls	Boys	Girls
Second	+	−	+	+*	+***	+
Third ..	+	+	+	+	+	+
Fourth	+	+	−***	−*	−	+
Fifth ..	+	+	−	+	−	−

*$P < .05$ ***$P < .01$

Once again results for the carpus differed from results for the epiphyses. In the second and third years of life correlations between height increment and carpal maturity increment, and between height increment and epiphyseal maturity increment, were usually of the same order (positive) but the latter tended to be larger than the former. In the fourth and fifth years a positive relationship between height and carpal development was maintained, whereas for height and epiphyseal development an inverse relationship became the rule rather than the exception. In the knee the reversal of the growth-maturation relationship is of questionable significance, but as regards the epiphyses of hand and wrist there can be no doubt that children whose *x* rays recorded an increase in maturity units grew *less* than the average amount during the fourth year.

This negative correlation may be explained as follows:

The epiphyses of long bones of the hand appear in a rush during the second and third years of life. They also appear earliest in children whose general rate of skeletal development, including linear growth, is rapid. By the time these children are three years old they have gained all the epiphyseal maturity units that the present method of assessment allows for (Acheson, 1954), yet they continue to increase relatively rapidly in stature. The slow maturers, who are also slow growers, are still ossifying some of their hand epiphyses during the fourth year. Therefore during this year children who are growing rapidly show no maturity gain, while those who are growing slowly still show such a gain and a significant negative correlation is found.

DISCUSSION

The range of variation of height in a group of pre-school children of the same age and sex is of the order of 4–5½" (Acheson, Kemp, and Parfit, 1955). In the present study we have shown that illness has a stunting effect on growth which is highly significant when the measurements of a large group of children who have been ill in a given year are compared with those of a large group who have remained healthy. However, in absolute terms, this stunting effect is rather less than ¼", and is, in fact, tiny when compared with the *natural* variation in height of the children. Therefore it is hardly surprising that Hardy (1938), and others who have used similar methods, have failed to find any difference between the mean height of a group of children who had experienced much sickness, and that of another group of the same age and sex who had enjoyed good health. Nevertheless this small effect is important, because in the absence of an equivalent delay in skeletal maturation, it seems likely to influence final adult stature.

In respect both of growth and of maturation boys appear to have been more affected by their illnesses than girls. This seems to be in accord with previous

studies of skeletal development in contrasted environments (Acheson and Hewitt, 1954a, b). The differing vulnerability of the sexes is also reflected in the mortality rates of early childhood when boys, though subject to similar environmental stresses, have a risk of death some 20 to 30 per cent. greater than girls (Registrar-General, 1954). The fact that the relationship between illness and the incidence of Harris's lines was more clearly demonstrated in girls may merely mean that some minor disturbance, not recognizable as "illness", which leave no trace on girls' bones, are sufficient to cause Harris's lines in boys, who also have a greater number of lines.

Since children with a rapid rate of skeletal maturation generally grow rapidly in height the apparent exceptions to this rule (see Table IX) call for a careful consideration of the method which we have used to measure skeletal maturity. Serial *x* rays of any part of the skeleton show that there are periods in a child's life when conspicuous changes occur in a short space of time and periods when very little change is detectable. For instance between Male Standards 7 and 10 of Todd's "Atlas" (1937) there is a considerable change in 18 months, and between Standards 22 and 26 there is very little change in 24 months. That is to say, there may be phases in the process of skeletal maturation analogous to the "shooting-up" phases of growth described by Harris (1947). Nevertheless, it is convenient to represent the skeletal maturation process by a variable which bears a linear relationship with chonological age. Though unsatisfactory in other respects, Todd's concept of "skeletal age" does fulfil this criterion. Our own method (which has the advantage of measuring skeletal maturation in terms not of age but of independent units of maturity) can be made to achieve the same object in two ways.

The easier method, which we have used hitherto, is to "weight" the maturity units awarded to separate parts of the skeleton so that the maturation assessment of the skeleton as a whole bears a linear relationship to age. In practice the overall assessments were based on three parts of the skeleton (hand, wrist, and knee) and carpal development has, of necessity, been given relatively great weight. This has two important disadvantages. In the first place carpal ossification may be more disturbed by adventitious factors than epiphyseal ossification. Secondly, carpal ossification does not necessarily have a direct bearing on the date of epiphyseal closure, and is therefore of questionable assistance in the prediction of final height.

A more difficult, but possibly more accurate method of assessing skeletal maturity would require detailed examination of all the epiphyses of the body throughout the growing period. In this way hitherto unidentified changes might be detected and maturity units scored during what now appear to be lulls in skeletal maturation.

Summary

An attempt has been made to measure the effect on growth and skeletal maturation of the illnesses recorded during approximately 2,000 child-years of the Oxford Child Health Survey. There was a small but definite diminution in the rate of growth during years in which an illness had been recorded. The amount of this loss was related to the severity of the illness and appeared to be slightly greater for boys than for girls. Since there is no commensurate reduction in the rate of skeletal maturation, it seems likely that adult height will be affected to some extent by even the minor illnesses of childhood. These effects of illness parallel those of adverse environment reported in earlier papers. Interruptions of growth but not of maturation were also found in years when transverse lines had appeared in the growing ends of the long bones. Such lines were frequently developed in conjunction with an episode of illness, particularly with bronchitis and the exanthemata. When this occurred, the effect was found to be greater than when an illness had left no mark on the bones, or when lines occurred without a recognized illness.

There were some slight indications that the maturation of the carpal bones was more susceptible to interruption by illness than that of the epiphyses of hand, wrist, and knee. But maturation of the epiphyses, as here measured, bore a much less stable relation to increase in height. The implications of this finding are discussed.

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CHANGING POPULATION OF MENTAL HOSPITALS

BY

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A number of publications in recent years have pointed out that, as a result of alterations in the laws relating to the care of the insane, of new methods of treatment, and of the changing public attitude to mental illness, important changes have occurred during the last 25 years in the type of patient admitted to hospital, and in the average length of stay. Fitzgerald (1954), Norris (1952), and Harris and Norris (1954) dealt with different aspects of this phenomenon, and Shepherd (1954) analysed changes occurring in one circumscribed region after an interval of 15 years. Goldhamer and Marshall (1949) discussed age-specific hospitalization rates for 19th and 20th-century America. Their conclusions are expressed in hospitalization habits for different age groups in the areas and periods concerned. They suggest that increased hospital facilities for the aged rather than increased arteriosclerosis may account for recent upward trends. Most British medical superintendents in their annual reports have had occasion to comment on the accelerated changes in the numbers and composition of their hospital admissions during the past 5 years.

In order to gain a clearer picture of the consequences which these tendencies have upon the composition of the mental hospital population it is necessary to carry out a census. Such a census was reported for hospitals in the Birmingham area by Cross (1954) in a survey which took especial note of the age distribution of patients, their length of stay, and the degree of over-crowding in male and female wards. The most comprehensive investigation of this kind to date has been the Registrar-General's statistical review (1953) which included a census of of all patients resident in mental hospitals at the end of 1949. This provides a valuable base-line for comparison with subsequent national and regional observations.

In the present small-scale survey a census was taken, in four mental hospitals serving the London area, of all patients resident on July 12, 1954, patients' present age, length of stay, diagnosis on admission and, in the case of male patients, previous occupation being noted. These figures have been compared with the Registrar-General's findings for 1949.

There has been a realtive increase in the proportion of older patients among the resident population (Table I). This fact is sufficiently well-known to hospital medical staffs, but an analysis of the sub-groups of patients in which the changes of age-bias are most marked reveals some additional information.

TABLE I

PATIENTS ABOVE AND BELOW THE AGE OF 65 YEARS

Source of Data	Percentage Patients	
	Under 65	Over 65
Registrar-General (1953)	72·4 (104,763)	27·6 (39,843)
Four Mental Hospitals ..	67·2 (6,044)	32·7 (2,949)

$\chi^2 = 115{\cdot}5$; $n = 1$; $P = 0{\cdot}001$

In the Registrar-General's returns there were more female than male patients (1·34 to 1). In the totals for our four hospitals this ratio was 1·53 to 1 ($\chi^2 = 37{\cdot}185$; $P = 0{\cdot}001$). It is questionable, however, whether the difference may not be attributable in part to local variation from the national average. Thus Cross found that in Birmingham hospitals in 1953 the female to male ratio was 1·32 to 1, which corresponds more closely to the Registrar-General's figure.

A comparison between the present survey and the population of the hospitals in the four Metropolitan Regions in 1949 is more meaningful. In the Registrar-General's 1949 Tables these figures are not given for total populations; but they are available for patients who on December 31, 1949, had been in hospital for one year or more (Table II).

TABLE II

PATIENTS IN HOSPITAL FOR ONE YEAR OR MORE

Source of Data	Males	Females
Registrar-General (1953) ..	18,621	28,536
Four Mental Hospitals ..	2,920	4,660

$\chi^2 = 0{\cdot}2614$; $n = 1$; $P > 0{\cdot}5$

In the present survey the increase in the preponderance of females in the long-stay population

is not significant when gross totals are considered. Among long-stay patients above the age of 65, however, the female preponderance is significantly increased (Table III).

TABLE III
LONG-STAY PATIENTS OVER 65 YEARS OF AGE

Source of Data	Patients over 65 years of age	
	Male	Female
Registrar-General (1953) ..	4,421	10,530
Four Mental Hospitals ..	619	1,953

$\chi^2 = 21{\cdot}73$; $n = 1$; $P = 0{\cdot}001$.

Whereas other studies have been focussed upon admission rates and length of stay, the present paper is concerned chiefly with the composition of that part of the patient population which could be regarded as "long-stay", and in particular with chronic schizophrenics. Table IV compares the age distribution of patients in the four hospitals with that of long-stay patients in the Metropolitan Regions (Registrar-General, 1953). The grounds for including patients in the category of schizophrenia in the present survey are described below (p. 190).

In schizophrenia there is a trend upwards in age in patients of both sexes. This trend is also shown by the proportion of schizophrenics over 65 years of age: 13 and 9 per cent. for males, and 33 and 17 per cent. for females, in the present sample and in the Registrar-General's data respectively. Figures for non-schizophrenic psychoses do not show this change. This increase in the number of elderly schizophrenic patients is no doubt a reflection in part of increased admissions of old people into mental hospitals, but may also be due to the increased longevity of long stay-patients. In the hospitals visited, 87·7 per cent. of the male and 90·0 per cent. of the female schizophrenics had been resident for more than 2 years.

Discharge Rate of Long-Stay Patients

An examination was made of all discharges during the 12 months preceding the survey of patients who had been in hospital continuously for 2 or more years. Expressed as a percentage of the number of long-stay patients resident in each hospital, these discharges were 1·8 per cent. of male patients and 1·6 per cent. of female patients, 20 per cent. of the men discharged and 41 per cent. of the women required further care, and only 35 per cent. of the men and 23 per cent. of the women were known to have made a full social recovery. Information about the remainder was insufficient to permit assessment of their measure of social adjustment after leaving hospital. It was evident that the great majority of patients who remain in hospital continuously for 2 years continue in hospital for a long period, if not for life.

Social Class

A striking finding of the Registrar-General's survey, and one in accord with several previous studies (Faris and Dunham, 1939; Felix and Bowers, 1948; Clarke, 1949), was the observation that the prevalence of schizophrenia appeared to be greatest in the lowest social classes: for males between the ages of 25 and 34 admission rates for schizophrenia were over five times higher in Social Class V than in Social Class I. By using the individual's previous occupation it was possible to allocate 81 per cent. of the male patients in our survey to one of the Registrar-General's five social classes.

TABLE IV
PERCENTAGE AGE DISTRIBUTION OF LONG-STAY PATIENTS

Sex	Age Group		0–24	25–34	35–44	45–54	55–64	65–74	75–	Un-known	Total
Male	Total	Registrar-General (1953)	2·17	10·63	19·67	23·14	20·26	16·43	7·30	0·41	100·01
		Hospitals	1·54	12·12	19·21	25·79	20·14	14·79	6·4	—	99·99
	Schizophrenics*	Registrar-General (1953)	3·05	19·17	30·24	25·5	13·16	6·67	1·85	0·45	100·09
		Hospitals	1·80	15·61	24·56	27·57	17·09	9·93	3·44	—	100·00
	Other Diagnoses	Registrar-General (1953)	1·55	4·53	12·11	21·45	25·31	23·40	11·18	0·37	99·90
		Hospitals	1·10	6·25	10·20	22·79	25·28	22·97	11·39	—	99·98
Female	Total	Registrar-General (1953)	1·22	5·26	13·00	19·80	23·64	22·57	14·33	0·18	100·00
		Hospitals	0·88	5·30	10·60	19·72	21·58	25·06	16·85	—	99·99
	Schizophrenics*	Registrar-General (1953)	2·24	11·15	22·65	26·29	20·59	12·29	4·64	0·15	100·00
		Hospitals	1·26	7·38	13·78	22·97	22·07	21·45	11·11	—	100·02
	Other Diagnoses	Registrar-General (1953)	0·74	2·51	8·51	16·78	25·07	27·36	18·84	0·19	100·00
		Hospitals	0·43	2·79	6·77	15·81	21·01	29·44	23·76	—	100·01

*Including paranoia and other paranoid states

The distribution of members of each social class was examined for four populations:

(1) All males over 15 years in the County of London (1951 Census).
(2) Male admissions diagnosed as schizophrenic during 1949 (Registrar-General, 1953).
(3) Short-stay patients in the present survey, who were diagnosed as schizophrenic.
(4) Long-stay patients in the present survey, who were diagnosed as schizophrenic.

Social Classes I and II contribute a disproportionately small number of cases of schizophrenia. It is conceivable that many patients belonging to these two classes may obtain treatment outside the provisions of the health service, but this is unlikely to account for the whole of the trend. It seems probable, moreover, that practically all members of Social Classes III, IV, and V who require hospital treatment for a schizophrenic illness are treated under the National Health Service. In these classes both the figures of the Registrar-General and those of the present survey show a raised incidence of cases of schizophrenia in Social Classes IV and V.

After a thorough study of the prevalence of mental disorders in a circumscribed community, Hollingshead and Redlich (1953, 1954) and Redlich, Hollingshead, Roberts, Robinson, Freedman, and Myers (1953) claim to have demonstrated two facts for the town of New Haven, Conn.: that the type of psychiatric treatment offered to patients differs with social class; and that in consequence of inadequate treatment patients from the lower social classes have a worse prognosis than those from the upper classes. The results of the present inquiry do not appear to support this conclusion (Table V): the numbers in Social Class III are a little greater among long-stay than among short-stay patients, and the numbers in Social Classes IV and V are a little smaller. This difference may be attributable to the greater availability of treatment in Great Britain since the introduction of the National Health Service.

Hollingshead and Redlich (1954) also showed that the mean age of schizophrenic subjects when first seen by a psychiatrist was inversely related to social class level. On this point the results of the present survey (Table VI) are not consistent, but the small numbers of patients in Social Classes I and II may explain the difference between the findings.

TABLE V

PERCENTAGE DISTRIBUTION BY SOCIAL CLASS OF MALE SCHIZOPHRENIC PATIENTS OVER THE AGE OF 15

Social Class	Males over 15 in London (Census, 1951)	Male Schizophrenics over 15		
		Admissions during 1949 (Registrar-General, 1953)	Present Survey	
			Short-Stay Patients	Long-Stay Patients
I	4·0	1·7	1·0	0·9
II	13·0	7·4	0·3	3·7
III	54·2	46·1	44·5	50·9
IV	11·9	16·6	16·6	12·8
V	16·9	28·2	35·2	31·6

TABLE VI

MEAN AGE OF SCHIZOPHRENICS ACCORDING TO SOCIAL CLASS

Social Class	Hollingshead and Redlich (1954)	Present Survey
I and II	29*	38·4†
III ..	31	33·9
IV ..	32	34·6
V ..	33	35·2

*Mean age of patients when first seen by a psychiatrist.
†Mean age of patients on admission to hospital.

In attempting to relate information about patients' social environment to their psychiatric history, the crude sub-division of cases by social class is only the first step. The next step would be to examine the groups of occupations severally, in order to ascertain whether specific occupations are associated with an unusually high or low incidence of certain disorders. This will not be possible until the analysis of the 1951 Census has been completed and the distribution of males among various occupations for the County of London has been made available.

It was possible, however, by using the figures given in the ONE per cent. Sample Tables of the 1951 Census (General Register Office, 1952) to derive approximate figures for the occupational distribution of male members of Social Class V in this area. When compared with the occupational distribution of schizophrenic patients of Social Class V in the present survey, the proportion of general unskilled labourers in each group was found to be very similar (75 per cent. of the total). Certain anomalies were apparent in some minor categories of work. For example, dock labourers, newspaper-sellers, and warehousemen contributed fewer schizophrenics than their numbers appeared to warrant; so also did the group of watchmen and caretakers. On the other hand, office cleaners, costers and hawkers, porters, and kitchen-hands contributed significantly more than their share of such cases. No explanation can be advanced for these indications of a differential association of schizophrenia with certain occupations, but they suggest a problem for future investigation.

Discussion

Any survey based upon a scrutiny of existing records must be limited in its accuracy by the quality of information available. In the present study the patients' sex, present age, and age on admission could be determined without difficulty, but in respect of diagnosis and occupation numerous ambiguities arose. Slater (1935), reporting on a similar survey, drew attention to the need to transpose archaic diagnostic terminology into contemporary terms, if psychiatric populations were to be compared. This is particularly the case with patients admitted to hospital over 20 years ago. Alternative diagnoses were most common in cases which to-day would be classed as one of the forms of schizophrenia. For the purpose of the present survey, patients with the following diagnoses on admission were included under this heading: dementia praecox, dementia paranoides, delusional insanity, paranoia, paraphrenia, paranoid state (unless specifically associated with depressive or senile psychosis), schizophrenia simplex, hebephrenia, primary dementia. Also included were cases of epilepsy and mental defect with "superimposed schizophrenia". The diagnosis of "secondary dementia" was attached to a number of long-stay patients. Examination of case-notes made it plain that most of these were also cases of schizophrenia: they were arbitrarily classified as such except for a few patients who were over 65 years of age on admission, who were counted as senile. The same procedure was adopted in classifying patients diagnosed on admission as suffering from "confusional insanity".

Organic and affective disorders presented fewer problems of classification, although there was again a variety in types of nomenclature.

Mention has been made above of the difficulty experienced in allotting patients to their appropriate social class. The data available on hospital record cards consist of statements of the patients' previous occupations, from which they can in theory be assigned to one of five social classes by reference to the "Classification of Occupations" (General Register Office, 1951). The limitations of this crude form of classification have been clearly expressed by Logan (1954), who indicates alternative methods of categorizing a patients' social milieu. Logan concludes that occupation remains the best practicable criterion for such classification. The five social classes thus distinguished remain so relatively heterogeneous in composition that it is remarkable that they are able to indicate a differential incidence of schizophrenia in the lowest class. It must be remembered in this connexion that the recorded "previous occupation" in a number of cases represents not the employment for which the patient was trained or in which he was originally engaged, but rather the last of a series of progressively lower jobs which he has held during the years of onset of his illness. This process is recognizable in only a few instances, but where it occurs it tends to give a downward bias to the determination of the social class of schizophrenic patients. It is felt that valid information about the influence of sociological factors upon the form and incidence of mental disorders must await a more exhaustive process of fact-finding than is possible in a survey based upon existing hospital records.

Summary

(1) A census of patients resident in four Metropolitan Mental Hospitals was carried out, and the figures compared with similar census data in the Registrar-General's 1949 review (published 1953).

(2) Significant increases were noted in the preponderance of female over male patients, and the proportion of patients over 65 years of age.

(3) The female preponderance was found to be especially marked in patients over 65.

(4) The increase of elderly patients in the "long-stay" population was found to be most marked in those diagnosed as schizophrenic.

(5) The census confirmed the findings of previous surveys that a disproportionately large percentage of schizophrenic patients is drawn from the lower social classes.

(6) In contrast with a recent American study, social class was not found to be correlated with length of stay in hospital.

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MENTAL ILLNESS AND SOCIAL CLASS IN BRISTOL

BY

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During the past 40 years a number of studies have supported the general hypothesis that the incidence of mental illness differs among people in various occupational groups. In particular, these studies suggest that schizophrenia is more common among the lower-paid groups but that manic-depressive psychosis is more or less equally distributed among all groups. The evidence for this is briefly summarized below.

Tietze, Lemkau, and Cooper (1942) have reviewed some early investigations, but, as Clark (1948) points out, their conclusions can be criticized on the grounds that no allowance was made for differences in age-distribution among the occupational groups. Later studies, however, are not subject to this criticism. Tietze, Lemkau, and Cooper (1941) showed that, among 180 psychotic and 234 neurotic cases active during the year 1936 and resident in a district of the city of Baltimore, a significantly high proportion were drawn from the lower income groups. Studying over 12,000 male first admissions to Chicago mental hospitals during the years 1922 to 1934, Clark (1949) showed a high negative correlation between income and the incidence of schizophrenia in nineteen occupational categories; between income and manic-depressive psychosis, on the other hand, the correlation was practically zero. This author also showed that very similar correlations held when only the lowest ten of the nineteen occupational groups were considered, thus disposing of the criticism that schizophrenics in the highest income groups are missed because they are cared for outside the city, for of the families in his ten lowest groups, practically none would have been able to afford such private treatment. Hollingshead and Redlich (1953, 1954), in a study of nearly 2,000 psychiatric cases (including both in- and out-patients) under treatment on a certain date in New Haven, Connecticut, found a very significant excess of schizophrenics among the lower social groups (definied in terms of occupation, education, and place of residence).

From Great Britain the only evidence bearing on this subject appears to be that of the Registrar-General (1953), derived from analysis of the Mental Health Index Cards for the year 1949. The figures (for males only) show the schizophrenia rate to increase markedly from Social Class I to Social Class V; the rates for manic-depressive psychosis and for neurosis show the same trend but to a much less marked degree. However, as the Registrar-General points out, various factors limit the trustworthiness of these figures:

(*a*) in 10 per cent. of the (male) cases, no occupation had been recorded and so no social class could be assigned;

(*b*) there is often doubt as to the accuracy of the occupation recorded, or the information is not sufficient to allow the class to be assigned with confidence;

(*c*) there is little uniformity of diagnosis throughout the country;

(*d*) the hospital facilities and hence the selection of patients for admission vary throughout the country.

The present study is thought worth reporting because it adds to the meagre British evidence, and, being concerned with the population of a single city served predominantly by one mental hospital, avoids some of the limitations of the Registrar-General's report.

METHOD

In principle, the method was to determine the social class and diagnosis of all male patients admitted during a 5-year period to mental hospitals who were resident in Bristol at the time of their admission. The investigation was confined to males because for married female patients the husband's occupation was not usually recorded in the statement of particulars. The details of technique are as follows:

(*a*) *Definition of a Case.*—For the purpose of the study, a "case" was defined as "a first admission of a patient, from an address within the city boundary of Bristol,* to a mental hospital". No simple definition of a psychiatric "case" can be entirely adequate. "Mental hospital" was taken to mean a hospital or nursing home which accepted wholly or predominantly cases recommended by a psychiatrist. There are several nursing homes in or near Bristol which accept aged patients who might in some instances be suffering from a psychiatric illness, but these nursing homes are not included in the survey. Patients attending the Bristol Day Hospital only were also excluded, but those admitted to the 80-bed Neurosis Unit were included.

(*b*) *Case-Finding.*—The survey was confined to a 5-year period, 1949–1953. This period was convenient because it centred in the 1951 Census and because during this time the psychiatric facilities in Bristol were practically unchanged. Of the psychiatric cases admitted to hospital, the great majority came to the Bristol Mental Hospital. Every effort, however, was made to trace cases admitted to private mental hospitals; the co-operation of the psychiatrists practising privately in Bristol and of the Medical Superintendents of nine private mental hospitals enabled this to be done with reasonable completeness—it is not possible to determine the precise coverage, but I believe that the 32 private-patient cases found represent the great majority of the total private cases. Altogether, 1,264 male cases were found.

(*c*) *Determination of Social Class.*—This was done from the occupation, according to the Registrar-General's "Classification of Occupations" (General Register Office, 1951). For students and school-boys, the father's occupation was used. In the case of retired men, the occupation which they had pursued for most of their working lives was used. Where there was any doubt about the correct grading of an occupation as recorded on the statement of particulars or on the Mental Health Index Card, recourse was had to the case history; if this proved insufficient, the patient or his relatives were seen by a social worker. In 32 cases (2·5 per cent.), however, it proved impossible to assign a social class; five of these were private cases.

As a check on the accuracy of the Mental Health Index Card, a social worker (familiar with the Registrar-General's classification of occupations and industries) interviewed 100 consecutively admitted patients (or relatives, if the patient was mentally inaccessible); the occupations as stated to her were then compared with those given on the index cards. In four instances, the information on the index card proved to be insufficient or misleading (*e.g.* a bricklayer's mate was described as a builder); but these errors were of the type that would have been checked from the case sheet and none would have led to a wrong final grading. This sample check suggests that the social class grading of all patients was reasonably accurate.

(*d*) *Diagnosis.*—The diagnostic categories were based on those of the International Statistical Classification of Diseases and Injuries (World Health Organization, 1949). Five categories were used:

Schizophrenia, (including schizo-affective disorder and paraphrenia),
Manic-depressive psychosis (including involutional melancholia and atypical and unspecified depression),
Senile and arteriosclerotic psychosis,
Neurosis (including neurotic or reactive depression),
All other diagnoses.

Psychiatrists are notoriously apt to differ on diagnosis because of the lack of objective criteria and of agreement on fundamental theory; these differences are increased by regionalism, and each centre of psychiatric activity is apt to develop its own local diagnostic climate (*e.g.* Strömgren, 1948). In the present study, however, the diagnoses were made for the most part by a group of physicians working together in the same hospital and with frequent opportunities for the interchange of clinical opinion. It would seem reasonable to suppose that these conditions lead to greater uniformity of diagnosis than obtains in the country as a whole. Apart from this, the greatest single diagnostic difficulty was the allocation of certain cases of depression to the manic-depressive or to the neurotic category; the doubtful cases, however, did not form more than about 10 per cent. of the numbers in the two categories.

Results

Table I (opposite) shows the observed and expected numbers of cases in different social classes. Because of the relatively small totals, the cases in Classes I and II have been combined, as have those in Classes IV and V. The "expected" number in a given social class is defined as the number of cases of a particular diagnosis that might have been expected to occur if the given social class had experienced within each age group the same case rate as that of the male population of Bristol as a whole. The data for the calculations was obtained from the 1951 Census One per cent. Sample Tables (General Register Office, 1952) and the 1951 Census County Report for Gloucestershire (General Register Office, 1954a). In calculating the expected numbers, the assumption was made that the age-distribution within the social classes in Bristol was the same as that in England and Wales as a whole.

Table I shows that schizophrenic cases were less than expected in the upper three social classes and much more than expected in the lower two, and that this distribution is very unlikely to have occurred from chance. For manic-depressive and senile psychoses, on the other hand, the observed distribution among the classes was not significantly different from that to be expected on a random distribution. For neurosis, the distribution is significantly different from random, but unlike schizophrenia, an excess of observed over expected cases occurs in Class III.

* The city boundary was altered slightly in 1951, but the effect is negligible.

TABLE I

OBSERVED AND EXPECTED NUMBERS OF CASES BY DIAGNOSIS AND SOCIAL CLASS

Males aged 15 and over, occupied and retired

Diagnostic Category	Number of Cases	Social Class			χ^2	P
		I and II	III	IV and V		
Schizophrenia	Observed (210)	17	106	87	28·35	$P<0·001$
	Expected	31·6	123·7	54·7		
Manic-depressive Psychosis	Observed (352)	66	189	97	1·02	$0·5<P<0·7$
	Expected	68·2	179·4	103·7		
Senile and Arterio-sclerotic Psychosis	Observed (145)	24	75	46	2·15	$0·3<P<0·5$
	Expected	30·4	67·7	46·9		
Neurosis	Observed (329)	39	200	90	7·45	$0·02<P<0·05$
	Expected	57·3	183·0	88·6		
Other Diagnoses	Observed (196)	32	89	75	13·30	$0·001<P<0·01$
	Expected	33·2	109·9	52·9		
All Cases*	Observed (1,232)*	178	659	395	14·99	$P<0·001$
	Expected	220·9	664·8	347·1		

* 32 cases for which a social class could not be assigned have been excluded.

In Table II, the results are presented as Standardized Morbidity Ratios* (that is, as the proportion of observed to expected cases expressed as a percentage).

TABLE II

STANDARDIZED MORBIDITY RATIOS BY DIAGNOSIS AND SOCIAL CLASS

Males, aged 15 and over, occupied and retired

Diagnosis	Social Class			Classified Cases	Number Unclassified
	I and II	III	IV and V		
Schizophrenia	54	86	159	210	8
Manic-depressive Psychosis	97	105	94	352	3
Senile and Arterio-sclerotic Psychosis	79	111	98	145	6
Neurosis	68	109	102	329	6
Other Diagnoses	96	81	142	196	9
All Diagnoses	81	99	114	1,232	32

Table III presents the same results in a different—and because of the relatively small numbers involved a rather less satisfactory—form. It may be compared with the Table on p. 89 of the Statistical Review for 1949 (Registrar-General, 1953).

DISCUSSION

These results confirm previous findings that different rates of mental illness exist among men in different occupational groups. In particular, they confirm the finding that schizophrenia is commoner among unskilled and semi-skilled workers than among the skilled and professional classes, but that manic-depressive psychosis is more or less equally common in all classes.

* Adopting the nomenclature suggested by the Registrar-General (General Register Office, 1954b), this ratio might better, perhaps, be called the Standardized Inception Ratio. A disadvantage of the term Standardized Morbidity Ratio is that its initial letters are the same as those of Standardized Mortality Ratio.

TABLE III

AGE-ADJUSTED RATES PER 100,000 MALES (OCCUPIED AND RETIRED, AGED 15 AND OVER) PER YEAR IN BRISTOL BY SOCIAL CLASS

Average of 5-year totals

Diagnosis	Social Class		
	I and II	III	IV and V
Schizophrenia	15·0	23·8	44·1
Manic-depressive Psychosis	45·0	48·6	43·7
Senile and Arterio-sclerotic Psychosis	15·1	21·2	18·8
Neurosis	29·5	47·2	44·3
All Diagnoses	131·6	160·6	185·7

The possible explanations of these findings have been discussed by previous investigators and will only be mentioned briefly here. In view of the accumulated evidence obtained in different populations by different methods, it seems reasonable to reject the suggestion that the apparent class differences are due to fallacies in technique (*e.g.* failure to allow for the alleged fact that in better-class patients, physicians tend to give the more hopeful diagnosis of manic-depressive psychosis rather than the gloomy one of schizophrenia). Hollingshead and Redlich (1954), while concluding that there are real class differences among schizophrenics under psychiatric care, raise the question

whether this would still be so in a "true prevalence study" (*i.e.* a study in which every member of a given population was psychiatrically examined so that cases of schizophrenia who had never come under care would be ascertained). But the idea of a true prevalence study is less simple than might at first sight appear. Quite apart from formidable practical difficulties (the population studied must number at least tens of thousands, every member of which should, ideally, be seen by a psychiatrist) there are theoretical difficulties.

A schizophrenic who has not come under medical care is likely to be a mild, "borderline" case; there are all grades between the individual who is merely odd, peculiar, or eccentric and the individual who is frankly schizophrenic; the decision where to make the dividing line is bound to be subjective, and yet that decision must have a dominating effect on the results, for the number of persons who are peculiar or eccentric greatly exceeds those who are undoubtedly schizophrenic. The problem has been discussed by Dunham (1953) who considers it more practical to take the view that mental illness may be defined by the fact of relatives seeking medical advice; on such a view, cases under psychiatric care give a true index of prevalence.*

If it is accepted that there are real class differences among psychiatric patients in the general population, what is their significance? Three main explanations have been advanced:

(1) It is suggested that "pre-schizophrenic" persons, because of their increasing social inadequacy, are able to hold only progressively poorly-paid employment, so that, by the time they become frankly ill, they are to be found in the less skilled and lower-paid occupations.

This is the hypothesis of "drift" which was also advanced to explain the findings of Faris and Dunham (1939) on the ecological distribution of schizophrenics in Chicago. The work of Hollingshead and Redlich (1954) and of Hollingshead, Ellis, and Kirby (1954), however, indicates that where there is a change in social class between a mentally ill patient and his parents, this is more often in the upward than in the downward direction.

(2) The class differences in schizophrenics reflect differences in treatment and rehabilitation. That such differences in treatment exist is undoubted (see, for example, Schaffer and Myers, 1954; and Redlich, Hollingshead, and Bellis, 1954), but it is hard to see why they should lead to class differences in schizophrenia and not in manic-depressive psychosis. Hollingshead and Redlich (1954), in their New Haven study, counted only those cases active on a particular day; as it is probably true that upper-class schizophrenics are more in and out of treatment, this might account for there being fewer upper-class schizophrenics in treatment at a given moment. But this argument would not apply to incidence studies such as that of Clark (1949) or the present one where the same class differences have been found. Again, it seems probable that upper-class patients are more likely to be treated as out-patients than are lower-class patients, and this might account for the class differences found in studies of hospitalized cases; but the same differences have been found in studies that include out-patient cases (Tietze and others, 1941; Hollingshead and Redlich, 1954).

(3) It is perhaps to the credit of epidemiologists in the field of psychiatry that they have been reluctant to accept the third explanation of the observed class differences—that these reflect the varying stress due to differences in social and economic conditions. The class differences observed in mental disorder are similar to those observed in conditions such as infant mortality, respiratory tuberculosis, chronic rheumatic heart disease, and chronic bronchitis (Registrar-General, 1954)—conditions in which social factors are usually presumed and in some instances have been demonstrated. Though some studies suggest a relation between certain types of mental illness and the cluster of factors at present subsumed under the title of "social isolation"*, not enough work has yet been done to allow reasonably firm conclusions to be drawn about the role of particular social factors in mental illness. It does seem reasonable to conclude, however, that such factors are present.

Summary

(1) The relation between social class and mental illness in Bristol has been studied in 1,264 male patients admitted to mental hospitals during a 5-year period.

(2) The distribution of schizophrenia among the classes differed very significantly from random, there being a social gradient with a marked excess of cases in Social Classes IV and V. The distribution of manic-depressive psychosis and of senile and

* For this conclusion to be true in Great Britain, two assumptions are necessary. Firstly, that there is no gross discrepancy between the required and the available psychiatric facilities—a reasonable assumption in Bristol; secondly, that general practitioners do not differ greatly in the use they make of the psychiatric facilities—a more doubtful assumption.

* Gerard and Houston (1953), Jaco (1954), Gruenberg (1954); see also Hare (1952) and Lemkau (1955) for a general summary and discussion, and an interesting article by Hebb (1955) reporting results of experimental isolation in animals and man.

arterio-sclerotic psychoses did not differ significantly from random. Among neurotics, there was a deficiency of cases in Social Classes I and II, and an excess in Class III. The total incidence of mental illness also showed a social gradient, with an excess of cases in the lower classes.

(3) The sources of error in the investigations are considered and the results briefly discussed.

(4) The results confirm those of previous investigations in other countries.

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RECORDS OF DEAF MUTISM IN NORTHERN IRELAND

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INTRODUCTION

A recent survey of deaf mutism in Northern Ireland has produced strong evidence that about a quarter of all born deaf mutes in the population are deaf because of non-hereditary causes (Stevenson and Cheeseman, in press). Lancaster (1951, 1954) has drawn attention to epidemics of deaf mutism in Australia, New Zealand, and Iceland, and has advanced presumptive, but nevertheless convincing, evidence that four out of five epidemics in Australia were the sequels to earlier epidemics of rubella. In his later study, Lancaster (1954) examined census and institutional data from several countries but did not include Northern Ireland. In the present paper we have examined the available sources of information relating to Northern Ireland to see if a high proportion of cases of congenital deafness can be explained by past epidemics.

SURVEY DATA

The survey of deaf mutism in Northern Ireland was designed to examine the genetical aspects of hereditary deafness. To ensure the inclusion of all affected members of the population, in addition to ascertaining persons known to be "born deaf", we also ascertained all those whose deafness was alleged to have had an onset after birth but before the age of 6 years. By extending the scope of the ascertainment, it was hoped to overcome two difficulties; the first was the reluctance of subjects and their relatives to admit a congenital abnormality and the second was the imperfect history of onset (coupled with the difficulty of diagnosing deafness in infants) likely to be given by adults about their own, or their relatives disabilities at birth.

By personal examination, and reference to hospital, school, and institutional records, and to general practitioners and consultants, it was possible to exclude, with reasonable confidence, all subjects for whom there was good evidence that the deafness was associated with or consequent upon other conditions such as cerebral palsy or meningitis—that is those in whom the deafness was known to be acquired. In addition we were able to identify clinically six subjects whose congenital deafness was not inherited. Two of these were deaf as a result of rubella during the mother's pregnancy, two after operation for Rh incompatibility, one was a cretin, and the last had congenital syphilis. For the purposes of the genetical study these were also excluded.

The details of the ascertainment and the problems of classification have been fully described elsewhere (Stevenson and Cheeseman, in press) and it is sufficient for the present purpose to note that we believe ascertainment was almost complete and that the above exclusions left a residual group of 509 subjects who were originally considered to represent adequately the hereditary deaf born in Northern Ireland.

The data from the families of these subjects undoubtedly pointed to recessive inheritance, and evidence from the deaf subjects who married and had children further suggested that there are several independent genes, possibly of different frequency in the population, which can determine deafness at birth. However, one feature of these data, and of similar data examined by Macklin (1947) and Hopkins (1947), was an unduly large number of sibships in which there was a single deaf born subject who had no other deaf born relatives and whose parents were not known to be related in any way. Undoubtedly some of the deafness in these was determined by inheritance, but we estimated that about 104 of the 424 living deaf born subjects (excluding the six cases known to be not inherited) were unlikely to be attributable to a single recessive gene. This proportion is unlikely to be materially altered by the hypothesis of several independent genes which was ultimately favoured. It is of course possible that some of the 104 were in fact acquired deaf subjects for whom misleading histories were obtained, but it seems unlikely that this source of error would account for many. Thus out of 430 living deaf born persons in the population there are probably about 110 deaf from non-hereditary causes, and in only six cases was the cause recognized, the other 104 cases could not be identified except in so far as they were members of a larger group of 202 offspring with no affected sibs born to unaffected parents.

Birth rank and age of mother have been shown to be of aetiological importance in several congenital defects, and it would obviously be of interest to see whether or not the distributions of the 202 deaf born, which include the 104 suspected to be not inherited, conform to random expectation. Unfortunately we have no information about age of mother, but the birth rank is available with few exceptions and in Table I this is given for 198 of the 202 deaf subjects. For a given sibship, size s, the random chance of any particular birth rank producing a deaf child is $1/s$; if there are n_s sibships of size s, the expected number of deaf born for each rank, 1, 2, 3 . . . . . s, is n_s/s. If the sibship sizes range from $s = 1$ to $s = t$, then for a given birth rank, r, the expected number of deaf born will be $\sum_{s=r}^{t} (n_s/s)$, and such expectations are also shown in Table I. The value of $\chi^2 = 0{\cdot}37$ suggests that it is most unlikely that the distribution of the 202 single deaf cases is other than random.

An hypothesis of epidemic deafness, such as supported by Lancaster's Australian findings, might imply a seasonal distribution of births of deaf persons. The month of birth was known for 176 of the 202 single cases and a very rough test for such seasonal occurrence was made by comparison of the observed distribution by calendar months with expectation that 1/12 of the total were likely to be born in each month. Observation and expectation are not materially different ($\chi^2 = 7{\cdot}54$, $DF = 11$, $0{\cdot}80 > P > 0{\cdot}70$), but this can be no more than an approximate test of significance because no account can be taken of the seasonal variation of the live birth rate during the period concerned.

TABLE I

BIRTH RANK OF DEAF BORN COMPARED WITH EXPECTED RANDOM DISTRIBUTION

Birth Rank	Deaf Born	
	No. Observed	No. Expected
1	60	61·71
2	46	44·71
3	33	31·71
4	23	22·71
5	15	15·71
6	10	10·91
7	6	5·24
8+	5	5·32
Total	198	198

$\chi^2 = 0{\cdot}37$
$D.F. = 7$
$0{\cdot}80 > P > 0{\cdot}70$

INSTITUTIONAL DATA

Protestant deaf children have been sent to the Ulster School for the Deaf in Northern Ireland since its foundation in 1831. Catholic deaf children have been sent for many years to two schools in Dublin, St. Joseph's and St. Margaret's, Cabra. The records of these schools were made available to us for the genetical study and were of great value in checking parents' and subjects' present-day statements with information recorded in the infancy of the deaf subjects. Some of the early records of the Cabra schools are no longer available, but the Ulster School records form a remarkable collection of continuous data relative to our present needs.

Each admission to the Ulster school was classified as "born deaf" or "acquired deaf" from information recorded at the time of admission and from what was known from other sources used in the recent survey. The admissions of the "born deaf" classified by year of birth are shown in Table II, excluding sixteen for whom this information was not available. This Table does not suggest that in any particular year an

TABLE II

DISTRIBUTION OF ADMISSIONS TO ULSTER SCHOOL OF BORN DEAF BY YEAR OF BIRTH

Decade of Birth	Year in Decade of Birth									
	0	1	2	3	4	5	6	7	8	9
181–	—	—	—	—	—	—	—	—	1	1
182–	—	—	—	—	—	3	2	6	4	6
183–	10	6	7	15	11	14	17	11	10 (1)	6
184–	6 (1)	6	7	9	15 (1)	5	9	15	11	12
185–	17	6	12	14	10	9	17 (1)	17 (1)	11 (2)	10 (1)
186–	8	13	9	17 (1)	9 (1)	8	13 (3)	6	7 (1)	12 (1)
187–	11 (3)	9 (2)	9 (1)	13 (2)	9 (1)	8 (3)	8 (2)	8 (1)	8 (2)	16 (3)
188–	9 (1)	9 (1)	9 (4)	5 (1)	11 (2)	10 (2)	6	5	9 (1)	13 (3)
189–	12 (2)	6 (1)	10 (2)	9 (2)	6	5	11 (1)	10 (1)	6 (1)	9 (1)
190–	8 (2)	7 (1)	11 (1)	8 (1)	4	9 (1)	10 (1)	8	5	6
191–	6	6 (1)	2	6 (1)	4	7 (2)	12 (2)	8	4 (2)	3 (1)
192–	8	1	3 (1)	6 (1)	4 (2)	2	3	6	2	6
193–	2	7	3	2	7	8	5	5	8 (1)	8
194–	6	8	6	5	5	12 (1)	8	3	1	3

Figures in brackets show number "born deaf" of consanguieneous parents; they are included in preceding figures. Consanguinity was recorded on admission sheets after 1857.
This Table does not include sixteen "born deaf" for whom the year of birth is unknown.

unusually large number of deaf children were born and who were subsequently admitted to the Ulster School; but the interpretation of this Table is difficult for several reasons. No allowance can be made for fluctuations in the birth rate, the relevant rate being restricted to the Protestant population. Again, the number of vacancies for new pupils was always limited and never necessarily large enough to absorb all applicants for admission. Finally, a small proportion of children were admitted from outside Northern Ireland.

Each year of birth was examined for evidence of a concentration of births of deaf infants in a particular season of the year. Unfortunately month of birth was not recorded in 92 cases although two-thirds of these omissions referred to births before 1840. Never more than five births were recorded in any one month. In fact, this figure was reached only twice, the first occasion being May, 1902, and the second December, 1916. The numbers of such births in months immediately before and after these maxima are of interest. In April and June, 1902, there were no recorded cases, and in November, 1916, and January, 1917, there was one case in each month. Only on six occasions were four deaf mute births recorded: March, 1846; May, 1847; January, 1852; April, 1880; April, 1920; September, 1938.

There were no deaf mute births in the months immediately before and after March, 1846, January, 1852, and September, 1938. There was one deaf infant born in April and one in June, 1847, one in March but none in May, 1880, and none in March and two in April, 1920.

It seems unlikely that these data alone can offer any evidence of deafness epidemics, but because of their limited representation of the community as a whole they do not rule out the possibility that such epidemics occurred.

Census Data

In his earlier work Lancaster (1951) reported the census enumerations of deaf mutes in New South Wales in 1911, 1921, and 1933. Here there was well defined evidence of maximum prevalence occurring at ages 10–14, 20–24, and 30–34 years of age respectively. This indicated an unusually high number of births of deaf mutes in the last few years of the 19th century, later described as the epidemic of 1899. The observations of Wickens (1927) and Wilson (Australia, 1941) led to a detailed study (Lancaster, 1954) of institutional data, from which it was concluded that there were subsequent outbreaks in 1916, 1924–5, and 1938–41. Except in 1916, these outbreaks were preceded by epidemics of rubella.

From 1851–1911 the enumeration of the deaf and dumb in the Irish censuses was supplemented by special inquiries about each person enumerated. The detailed procedure, which did not materially alter during the 60 years, has been described by the Census Commissioners for Ireland (1854) and discussed at length by Wilde (1853, a, b). Potentially the available data were of considerable value for genetical examination. Successive reports emphasized that their value depended upon the completeness of the original enumeration and upon the efficiency of the subsequent classification of the deafness encountered. For reasons which will emerge, it is unlikely that the ascertainment was ever complete or the classification ever perfect. Nevertheless it is clear, particularly from Wilde (1853a), that the supplementary inquiries were conscientiously undertaken, even to the extent of obtaining local medical opinion in cases of clinical doubt. Unfortunately the original records are no longer available (Registrar-General for Northern Ireland, 1954) and thus examination of the data must be restricted to that published in the census reports. In the latter the deaf individual, rather than his or her sibship, was usually the unit of reference so that further analysis is largely limited to examination of the prevalence of deaf mutism in population groups.

In the Irish census reports, the deaf and dumb were classified as "congenital", "acquired", or "uncertain or unknown". In what follows, these have been described as "born deaf", "acquired deaf", and "doubtful" to bring the terminology into line with that of the main survey. The classification and the difficulties presented in classifying particular individuals are dealt with in detail by the Census Commissioners for Ireland (1854) and by Stevenson and Cheeseman (in press). The doubtful group in the census reports, which never exceeded 7 per cent. of all deaf and dumb, was composed largely of persons who were enumerated on routine census schedules but for whom answers to supplementary inquiry could not be obtained.

Table III (opposite) sets out the prevalence rates at each census according to the type of deafness recorded.

It is clear that in 60 years there has been very little change in total prevalence. However, the rates suggest a change in the ratio of "born deaf" to "acquired deaf" which may be real or which may reflect more efficient diagnosis. Consistently there was relatively more deafness enumerated among men than among women.

The information collected which is of specific interest in the present context is the age, sex, place of residence, and classification of type of deafness.

TABLE III

PREVALENCE OF DEAF AND DUMB PERSONS IN IRELAND BY CLASSIFICATION OF CONDITION, 1851–1911

(Number of affected persons per 100,000 of population)

Sex	Classification	Census Year						
		1851	1861	1871	1881	1891	1901	1911
Male	"Born Deaf"	70	80	73	68	59	54	58
	"Acquired Deaf"	9	11	18	16	17	18	19
	"Doubtful"	6	3	2	1	1	4	2
	Total	84	95	93	85	78	75	80
Female	"Born Deaf"	49	62	57	54	50	44	48
	"Acquired Deaf"	8	11	14	14	15	16	14
	"Doubtful"	4	3	2	1	1	3	2
	Total	61	76	72	69	65	63	63
Total	"Born Deaf"	59	71	65	61	55	49	53
	"Acquired Deaf"	8	11	16	15	16	17	17
	"Doubtful"	5	3	2	1	1	3	2
	Total	72	85	83	77	72	69	72

Unfortunately the age and sex distributions are available for the deaf born, only for the whole of Ireland and only for the years 1881, 1901, and 1911. Moreover in these distributions the doubtful cases are included with the "born deaf". Table IV shows that where the classification by age can be made for the "born deaf" (including doubtful), the higher prevalence among men is a feature of most age groups, and that there was, with few exceptions, a lower prevalence rate in 1901 and 1911 than in 1881. As in Table III, the secular trend may be a result of improved diagnosis but this seems unlikely to be an explanation of the sex difference.

TABLE IV

PREVALENCE OF "BORN DEAF" AND "DOUBTFUL" IN IRELAND CLASSIFIED BY AGE AND SEX, 1881, 1901, AND 1911

(Number of affected persons per 100,000 of population)

Age Group (yrs)	Sex								
	Male			Female			Total		
	1881	1901	1911	1881	1901	1911	1881	1901	1911
0– 4	5	5	5	7	2	4	6	3	5
5– 9	48	28	36	37	29	28	43	29	32
10–14	64	48	57	45	41	51	55	45	54
15–19	69	67	52	52	55	49	60	61	51
20–24	79	57	62	54	41	50	66	49	56
25–29	89	70	77	76	51	53	82	60	65
30–39	99	72	79	80	55	57	89	63	68
40–49	91	75	73	82	65	61	86	70	67
50–59	105	92	80	84	60	74	94	75	77
60–69	95	73	95	60	58	72	77	66	83
70+	59	65	75	54	72	55	56	69	64
Total	69	58	61	56	47	49	62	52	55

In all three years 1881, 1901, and 1911 the prevalence among the very young was never more than 7 per 100,000, this is undoubtedly due to a low standard of ascertainment and failure to recognize deafness in infants. After the age of 5 years the prevalence rises fairly steadily to a maximum at ages 50–59 in 1881 and 1901, and 60–69 in 1911.

Other influences being constant, evidence of epidemic deafness would be revealed by high prevalence rates in the same generation at each census. Thus an unusually high rate in a given age group in 1881 would be followed by similary high rates in age groups 20 years older in 1901 and 30 years older in 1911. In the Table the nearest approach to such a series is seen in the rates of 89, 75, and 83 per 100,000 at ages 30–39, 50–59, and 60–69 in 1881, 1901, and 1911 respectively. In these the last two were the maxima of the age-specific rates in the census years concerned; in 1881 the rate of 89 per 100,000 is an irregularity in the gradual increase in the rates with age. Although this observation might be suggestive, the size of the rates is clearly not indicative of any heavy epidemic, and as in the last two censuses it represents the natural maxima of the age-prevalence curve, interpretation depends mainly on the observation of the high level in 1881 occurring at an age which disturbs the general upward trend of the rates with increasing age. If this high rate was due to an earlier epidemic of deafness at birth, then the epidemic must have occurred in the decade 1842–1851, and the school data would be suggestive of 1846 or 1847. Numerically, however, such an epidemic, even if real, was unimportant, and it occurred too early to have an effect on the current survey of deafness in Northern Ireland.

Certainly there is nothing in Table III comparable with the epidemic evidence of the census data of New South Wales. Here the actual number of male

deaf mutes enumerated [Lancaster (1951) does not quote the rates] was 54 at 10–14 years of age in 1911 compared with 34 and 35 in the adjoining 5-year age groups, 69 at 20–24 in 1921 compared with 30 and 36, and 78 at 30–34 in 1933 compared with 44 and 44. For females the numbers were 57 in 1911 compared with 25 and 29, 46 in 1921 compared with 27 and 23, and 62 in 1933 compared with 25 and 27.

Summary and Conclusions

An examination of the Irish census enumerations from 1851 to 1911 with particular reference to the age distributions available for 1881, 1901, and 1911, gives no indication of any generation of people in whom a particularly high proportion were "born deaf".

Similarly, admission records of a school for the deaf fail to reveal evidence of an unduly large number of children having been "born deaf" in any particular year or calendar month.

These findings are of interest as presumptive evidence exists that in about one-quarter of the deaf born persons at present living in Northern Ireland the deafness was not of genetical origin.

The hypothesis that some of this non-genetically determined deafness is attributable to maternal infections in early pregnancy is thus not supported by the census and school data. However, they cannot exclude such an hypothesis because of their inherent limitations.

Because the deafness of genetical and non-genetical origin cannot be efficiently distinguished, direct examination of the latter is not possible in the majority of cases. However the distributions by rank and season of birth of a group of living deaf born persons with unaffected sibs and parents, of whom probably one-half are deaf from non-genetical causes, could easily have occurred by chance ($P > 0{\cdot}7$).

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MEASUREMENT AND INTERPRETATION OF SUBCUTANEOUS FAT, WITH NORMS FOR CHILDREN AND YOUNG ADULT MALES

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There is need for a simple and accurate measurement of surface body fat in view of the importance of this tissue from the nutritional and other points of view. Thus body fat, or its change, reflects the balance of an individual's energy intake and output, and this energy balance has been found to be the main determining factor in nutritional adequacy—at least in European countries (Berry, 1951). Apart also from the functional aspect of body fat as an energy reserve and as a thermal insulator, it appears to be related to the tendency towards the development of certain diseases and freedom from others (Draper, 1924; Freeman, 1934), and its excess is associated with a reduced expectation of life. Surface fat has also been shown to be one of the chief distinguishing features of physical types (Hammond, 1953a). It would be useful, therefore, to have a convenient and accurate measurement of surface fat and also to have standards against which to compare observed results.

Some inferences can be made concerning body fat from the relations between certain body measurements and weight or from the changes in these measurements. Specific gravity of the body is also claimed to indicate body fat. However, at the best, these are indirect measurements, which are complicated in the former case by growth and physical type, and in the latter by variations in the "lean body mass". In adults, changes in weight are mainly due to loss or gain in fat so that these two functions over-lap to a considerable extent (Edwards, 1950), but in children, weight, growth, and fat need to be considered separately. In addition to caliper measurements of body fat, other possible methods include measurement of fat thickness from *x*-ray plates, and estimation of body fat from biochemical changes involved in fat metabolism.

If we confine ourselves to the caliper measurement of subcutaneous fat, the major problems are those of measuring the skinfold accurately at any one point and of determining the number of sites required in order to assess the total surface fat. We also need to know how caliper measurements of body fat vary between the sexes and at different ages, and finally it would be useful to be able to translate the caliper measurements into actual amounts of subcutaneous fat present.

The present paper, therefore, gives the mean caliper measurements for boys aged 2–18 years, a group of adult male factory workers, and girls aged 2–15 years, taken at six sites which have been found to be representative of the results obtained from many sites. The results have also been translated into terms of actual fat thickness as indicated by uncompressed fold thickness measured from *x*-ray photographs.

Experimental Method

For those not familiar with the technique of taking fat measurements the procedure is to lift a fold of skin and subcutaneous tissue clear of the underlying (muscle) tissue between the thumb and forefinger of the left hand, at the same time applying the spring calipers pincer-fashion to the parallel-sided fold so produced. (See Plate 1, p. 143, Edwards, Hammond, Healy, Tanner, and Whitehouse, 1955).

In order that the measurements obtained by different observers should be comparable, they must be taken in a standard way at recognized sites using an instrument whose degree of compression of the fold is known. As a result of a number of trials extending over several years, a new dial-type caliper has been produced, known as the M.R.C. or Harpenden skin-fold caliper, having plate sizes 6 × 15 mm. and pressure 10 g/mm.[8]

This instrument, and also a modified Franzen-type spring-caliper studied in the above report by Edwards and others, were used in the present study. The results obtained with the earlier Franzen caliper were calibrated against the new caliper in producing the means, etc., of Table IV.

Details of the sites used are given in the Appendix. They are similar to those used at various times by Edwards (1950), Berry and Cowin (1951), Hammond (1953a), and Edwards and others (1955), with certain additions.

Accuracy of Measuring Technique.—Three separate tests of accuracy were applied during the collection of the present data by the author (who also took part in the trials reported by Edwards and others). As the instruments used were of the same type, and as the levels of accuracy obtained in the present trials agreed fairly closely with the above, summarized results only are presented. Joint trials were also undertaken with Drs.

TABLE I

STANDARD DEVIATION OF MEASURING DIFFERENCES (mm.)

Caliper	Observers	Biceps	Triceps	Sub-scapular	Supra-iliac	Sub-costal	Abdominal	Subjects
Franzen	Different	0·95	0·89	0·81	1·59	—	1·09	60 boys
		0·50	0·97	0·96	—	0·67	1·02	47 boys and girls
	Same	0·63	0·77	—	—	—	—	60 boys and girls
M.R.C.	Same	0·54	0·72	0·38	0·50	0·60	0·60	34 boys

Berry and Cowin (who contributed many of the measurements in the table of norms) to ensure that our measuring standards were comparable. One difference between the present trials and those reported by Edwards and others was that the results given in Table I were obtained with unmarked sites and therefore differences of location contributed to the errors (this is especially true of the triceps and supra-iliac sites where small differences in position affect the measurements considerably).

(1) Choice of Measuring Sites and Assessment of Their Representativeness

The usual purpose of reporting fat measurements is to indicate the general level of surface body fat rather than the particular reading at any one site, hence it is necessary that the site measurements should apply (with appropriate conversion) to the body as a whole.

If an adequate external criterion of total body fat (or of surface fat) were available to use as a standard, it would be possible to compare the skinfold measurements obtained at any site with this figure, but in the absence of such information it is necessary to use an internal criterion. The validity or representativeness of different sites can be determined by correlating the results for different measurements with each other or with the sum of the measurements taken at a number of sites. An alternative procedure is to see to what extent a general factor underlies all the measurements and then to determine which measurements indicate this factor most closely; in the same way intelligence is determined as a factor underlying a number of intellectual tests, each of which is an imperfect measure of the factor itself. The factor so derived is really a kind of weighted average in place of the simple total of fat measurements. A measurement can be representative of the total surface fat present, or it can be diagnostic of changes in body fat. Both these aspects have been investigated by correlating batteries of fat measurements and also by correlating changes in these measurements.

Sample.—The correlations were based on groups of children or adults drawn from the following sources:

(1) Leeds babies followed up from 1 to 5 years (Hammond, 1952).

(2) Children aged 5 to 15 years attending council schools in poor, average, and good areas of a number of towns (Hammond, 1953b).

(3) Children aged 5 to 17 years attending independent fee-paying schools, including boarders and day-scholars (Hammond, 1953b).

(4) Children aged 3 to 19 years attending a branch of the National Children's Home.

(5) Children aged 7 to 17 years attending an open-air school for debilitated children, together with a normal control group.

(6) Adult women hospital patients, excluding those with endocrine disorders (Edwards, 1950).

The numbers in each group are given in the Tables of results.

Most of the cross-sectional measurements were based on different children at the different ages, but a few (less than 5 per cent) of the same children appeared in different age groups. The analysis of changes in body fat was made on children of Groups 4 and 5 above. Age norms for measurements at six sites were obtained on the above groups together with five sites for a group of factory workers in light industry (Berry and Cowin, 1954). The total number of subjects was just over 4,500. In no case was there any special selection within the school or group (except that children suffering from specific diseases in Group 5 above were excluded).

In two age groups the children were drawn mainly from the higher social classes and in these cases the results have been weighted to conform to the social distribution of the rest of the sample (*i.e.* composed mainly of council school children). Similarly the results from clinically poor groups were never allowed to contribute more than 15 per cent. of any age group.

Results

Relations between Fat Measurements at Different Sites.—The eight tables of correlations between fat measurements for the different groups are available from the author if required.

Table II (below) gives saturation coefficients for the general factors obtained from these Tables, and the correlations between each measurement and the sum of all the measurements.

Table III (below) gives corresponding saturations for the general factor for changes in body fat and the correlations between the individual measurement changes and the sum of all the changes.

The correlations for all ages are remarkably high [average $r = 0{\cdot}75$ ($0{\cdot}63$ to $0{\cdot}84$)], showing that the influences of conditions specific to any one region, as, for example, the effect of exercising the underlying muscles, is small compared with the overall differences. On average, the variance of the general factor accounts for 75 (63 to 84 per cent.) of the total variance. In fact, the fat measurements at different sites show such close agreement that almost any one measurement could be substituted for the rest without great loss. Correlations between single sites and total fat are of the order $0{\cdot}8$ to $0{\cdot}9$, and

TABLE II

GENERAL FACTOR SATURATIONS AND CORRELATIONS BETWEEN FAT MEASUREMENTS AT EACH SITE AND THE TOTALS OF ALL MEASURING SITES

Sex		Male				Female			
Age Group (yrs)		6	7–11	9–12	15–18	7–11	16–29	30–44	45+
Forearm (outside)	Saturation	—	—	0·955	0·915	—	0·915	0·654	0·703
	Correlation	—	—	—	—	—	0·914	0·663	0·764
(inside)	Saturation	—	—	0·968	0·881	—	—	—	—
	Correlation	—	—	—	—	—	—	—	—
Biceps	Saturation	0·802	0·911	0·898	0·908	0·884	—	—	—
	Correlation	0·757	0·911	—	—	0·889	—	—	—
Triceps	Saturation	0·713	0·856	0·880	0·881	0·867	0·912	0·866	0·850
	Correlation	0·760	0·897	—	—	0·889	0·901	0·851	0·834
Sub-scapular	Saturation	0·772	0·896	—	—	0·907	0·955	0·947	0·926
	Correlation	0·789	0·942	—	—	0·881	0·947	0·936	0·900
Supra-iliac	Saturation	—	0·891	—	—	0·912	0·913	0·867	0·805
	Correlation	—	0·943	—	—	0·890	0·914	0·878	0·768
Sub-costal	Saturation	0·820	—	—	—	—	0·874	0·871	0·850
	Correlation	0·811	—	—	—	—	0·879	0·877	0·862
Abdominal	Saturation	0·849	0·933	0·915	0·642	0·920	0·940	0·876	0·911
	Correlation	0·852	0·958	—	—	0·894	0·931	0·869	0·889
Thigh	Saturation	—	0·883	—	0·641	0·889	0·830	0·853	0·810
	Correlation	—	0·954	—	—	0·858	0·860	0·856	0·859
Chest	Saturation	—	—	0·878	0·715	—	0·898	0·830	0·854
	Correlation	—	—	—	—	—	0·886	0·817	0·822
Number Examined		346	401	31	100	400	58	52	46

TABLE III

MEAN GENERAL FACTOR SATURATIONS FOR ANNUAL CHANGES IN BODY FAT AND CORRELATIONS WITH TOTAL FAT CHANGE

Sex		Male					Female			
Age Group (yrs)		4	4–8	8–11	11–14	14+	4	4–9	10–12	12–14
Biceps	Saturation	0·488	0·683	0·844	0·679	0·527	0·400	0·678	0·676	0·709
	Correlation	0·543	0·765	0·914	0·759	0·561	0·465	0·739	0·695	0·818
Triceps	Saturation	0·340	0·744	0·673	0·826	0·592	0·673	0·836	0·687	0·705
	Correlation	0·521	0·790	0·791	0·918	0·739	0·701	0·927	0·700	0·836
Sub-scapular	Saturation	0·939	0·644	0·750	0·816	0·565	0·492	0·663	0·760	0·692
	Correlation	0·943	0·700	0·832	0·913	0·616	0·571	0·720	0·834	0·732
Supra-iliac	Saturation	0·781	0·544	0·881	0·784	0·337	0·866	0·511	0·667	0·498
	Correlation	0·803	0·724	0·882	0·854	0·459	0·779	0·616	0·814	0·641
Sub-costal	Saturation	0·817	—	—	—	—	0·519	—	—	—
	Correlation	0·864	—	—	—	—	0·626	—	—	—
Abdominal	Saturation	0·973	0·728	0·823	0·690	0·750	0·430	0·593	0·796	0·774
	Correlation	0·951	0·819	0·895	0·770	0·877	0·671	0·750	0·827	0·832
Number Examined		31	33	51	67	36	37	62	44	49

the best combinations of two sites in most batteries give multiple correlations of the order 0·95, whilst three increase the multiple correlation to 0·97 or over.*

Although the best measurements vary somewhat according to the total battery and according to the individuals (male or female, children or adults) the results show that the sub-scapular and abdominal measurements followed by biceps and either sub-costal or supra-iliac measurements give the best indication of total fat.

It is worth noting that in the women's measurements the saturations for the general factor for the small battery of tests agree very closely with the correlations between the measurements and the total of 56 measuring sites (Table II), showing that a severe curtailment of the number of measurements has left the diagnostic value of the separate measurements practically unchanged compared with the wider criterion based on measurements taken over the whole of the body.

When the general factor was extracted, the residual variance showed the presence of a secondary factor differentiating between fat deposition on the trunk or on the limbs. All the tables which included limb and trunk measurements supported this distinction without significant exception. The variance of the second factor averaged 3·7 (1·4 to 8·3 per cent.) of the total variance. The number of measuring sites tested was rather limited for the purpose of defining a second factor, but the biceps measurement had the highest factor saturation for the limb component in the majority of tables. For the trunk component the measurement with the highest saturation depended upon the combination of trunk measurements used, and the choice of measurements for the purpose of defining the trunk component must, therefore, be left open. A wider selection of sites would be required to deal with the distribution of body fat in any detail, but the appearance of a division into trunk and limb groups suggests that at least one limb and one trunk measurement should be included in any combination intended to be representative of total body fat, since this would cover the most important variation in the pattern of fat distribution.

Changes in Body Fat.—Another and perhaps more important aspect of body fat is its change in individuals over a period. Changes in one individual may be slight compared with the differences between individuals, but they may be more important nutritionally. One could assess a person's total fat from the three most representative measurements above and repeat the measurements at intervals along with weight to determine changes in conditions. However, the sites which are most representative of the cross-sectional measurements may not be the best ones to reflect change in total fat or change in weight; hence fat measurements at the five or six sites used in the cross-sectional studies were taken monthly or quarterly for 2 years in two different studies involving groups of children of different ages. The changes at different sites were correlated with each other over the 24 months. As there were in all sixteen tables of correlations these are not reproduced;* instead, the correlations between each site and the sum of the measurement changes from all sites, and also the general factor saturations for each group are reproduced (Table III).

The rather uneven grouping of ages in Tables II and III is due to the fact that the results were collected from a variety of studies undertaken at different times for different purposes. The ranges were chosen to avoid a large scatter in ages at points where the mean measurements were changing. The analysis results from the various groups are reproduced to show the general level of consistency in the behavious of fat measurements at different sites.

Here the changes in each measurement are not as closely related as are the cross-sectional measurements [mean $r = 0{\cdot}56(0{\cdot}31$ to $0{\cdot}75)$], partly because the measuring errors play a greater part. Again, the triceps, scapular and abdominal fat (umbilical region) are the most closely related with the general change (as assessed from the sum of the changes in fat measurement and according to the general factor corresponding to the overall fat change), but the results vary more from group to group. Further, the general factor accounts, on average, for only 49 per cent. of the total variance, compared with 75 per cent for the cross-sectional results.

Measured changes in an individual's subcutaneous fat at any site do not, therefore, indicate total change as closely as the individual measurements represent the present fat rating of the person in relation to a group standard. The practical outcome is that it is more important to use several sites when determining fat changes than when studying cross-sectional data. This is also made necessary because the errors of measurement of fat change are considerably higher in relation to the total variance.

Correlations between fat change and weight change in children were low and often negative [mean $r = 0{\cdot}40(-0{\cdot}39$ to $+ 0{\cdot}90)$] depending on the sex and ages studied. This is because weight

*Detailed results of coefficients and multiple correlations for different combinations of sites are available if required, from the Author, Ministry of Health, Savile Row, London W.1.

*They are available from the Author.

gain in children is mainly due to growth of muscle and skeleton. Further, the change in the mean body fat does not follow the pattern of weight change with age, for in some children the phenomenon of "bolting" occurs, and growth apparently continues at the expense of body fat as shown by the negative correlations, and in others body fat increases markedly after growth ceases. Even the correlations between change in body fat and weight gain per unit gain in height were centred around zero [mean $r = 0{\cdot}03$ ($-0{\cdot}24$ to $+0{\cdot}22$)].

The above results show that the sites which were initially chosen largely for convenience (as entailing a minimum of undressing and discomfort to the subject) and also for ease in making a parallel-sided fold have proved to be highly representative of all measuring sites. We can therefore, be fairly confident that if we measure individuals or groups at these sites the results will give much the same relative positions as if we measured them at many sites.

Although the data are insufficient to be able to say that the particular measuring sites chosen are the best of all the possible ones, yet the fact that these sites are representative of general conditions increases their usefulness. Since, also, these sites have been studied more extensively than any others by other workers (very similar sites have been included among those reported in all the major published studies in this country), there is much value in keeping to these measurements (if necessary with the addition of other sites for particular purposes) for general nutrtional survey work.

(2) Age Norms for Body Fat

Means and standard errors for caliper measurements taken at six sites studied in different age groups using the standard M.R.C. calipers (or results from Franzen-type calipers transformed to the M.R.C. equivalents) are given in Table IV.

Fig. 1, and Figs 2 and 3 (overleaf), show the age trends for the different fat sites for boys and girls. Sex differences are shown not only in the general amount of body fat but also in the pattern of change with age. Apart from irregular fluctuations, probably due to sampling, the girls decrease very slightly in fat from 2 years to around 5 years, and then increase continuously to age 15 years when the data stop. This is true of all measuring sites but the arm measurements show much slighter increases than the trunk ones. In the case of boys two trends are apparent, one in the trunk fat (Fig. 2), in which measurements decrease to age 7 years then increase rapidly to 11 years and more slowly to 17 years. The

TABLE IV

CALIPER MEASUREMENTS OF SKINFOLD THICKNESS (PRESSURE 10g./mm.²) FROM AGE 2 ONWARDS

Sex	Age (yrs)	Number Examined	Measurement Site											
			Biceps		Triceps		Sub-scapular		Supra-iliac		Sub-costal		Abdominal	
			Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Male	2	89	5·59	0·12	10·10	0·16	5·55	0·09	5·12	0·14	4·53	0·08	6·77	0·19
	3	28	4·99	0·21	9·32	0·28	4·73	0·18	5·05	0·26	3·65	0·12	5·99	0·36
	4	43	4·94	0·17	9·34	0·23	4·78	0·14	4·62	0·20	3·57	0·12	5·81	0·28
	5	49	4·50	0·15	9·13	0·23	4·97	0·15	4·61	0·20	3·74	0·09	5·96	0·27
	6	399	4·31	0·05	8·23	0·08	4·58	0·05	4·39	0·07	3·70	0·03	4·92	0·09
	7	65	3·94	0·15	7·88	0·23	4·51	0·17	4·35	0·18	3·40	0·15	4·70	0·24
	8	65	3·86	0·15	7·56	0·23	4·46	0·17	4·29	0·18	3·54	0·15	5·13	0·24
	9	130	4·13	0·11	8·21	0·16	5·03	0·12	5·12	0·13	4·50	0·11	5·61	0·17
	10	472	4·06	0·06	8·20	0·09	5·04	0·06	5·05	0·07	4·28	0·06	5·82	0·09
	11	235	4·55	0·10	8·94	0·18	5·22	0·12	5·21	0·15	5·09	0·08	6·25	0·16
	12	162	4·10	0·12	8·45	0·22	5·20	0·15	5·22	0·18	5·22	0·10	5·99	0·20
	13	110	4·20	0·10	8·11	0·22	5·29	0·10	5·24	0·10	5·20	0·10	5·82	0·16
	14	1,056	4·19	0·03	7·91	0·07	5·54	0·03	5·23	0·03	5·17	0·03	6·04	0·05
	15	98	3·32	0·06	6·30	0·22	5·26	0·09	4·94	0·13	4·78	0·12	5·46	0·19
	16	68	3·41	0·08	6·22	0·27	6·27	0·11	5·45	0·16	5·26	0·14	6·10	0·23
	17	275	3·58	0·08	6·40	0·14	6·44	0·06	5·52	0·09	5·84	0·08	7·22	0·12
	18	181	3·11	0·09	4·81	0·19	6·07	0·09	5·00	0·13	5·14	0·11	5·53	0·16
	Adults	228	3·22	0·09	5·83	0·18	7·95	0·09	—	0·12	7·81	0·10	8·80	0·15
Female	2	46	5·39	0·20	10·90	0·34	—	—	—	—	—	—	—	—
	3	38	5·04	0·24	9·70	0·40	5·05	0·27	5·52	0·35	4·33	0·18	6·80	0·42
	4	44	5·29	0·21	10·24	0·35	5·20	0·23	5·30	0·30	4·20	0·16	7·20	0·37
	5	45	4·94	0·26	9·42	0·37	5·18	0·33	5·12	0·34	3·97	0·23	6·18	0·53
	6	39	5·40	0·28	9·57	0·39	5·28	0·35	5·65	0·35	4·60	0·25	7·60	0·60
	7	60	5·20	0·20	9·39	0·31	5·39	0·25	5·94	0·26	4·55	0·19	7·08	0·48
	8	21	5·35	0·38	10·10	0·55	6·20	0·45	6·41	0·45	5·07	0·30	8·06	0·80
	9	80	5·60	0·17	10·25	0·36	6·27	0·22	6·80	0·22	5·34	0·16	8·39	0·42
	10	88	5·67	0·24	10·36	0·34	6·50	0·26	7·04	0·31	5·08	0·30	9·31	0·46
	11	94	6·21	0·23	10·64	0·33	7·73	0·25	7·92	0·30	5·69	0·28	10·88	0·45
	12	68	5·64	0·24	10·06	0·38	7·54	0·47	7·37	0·43	5·95	0·43	11·32	0·60
	13	65	6·18	0·24	10·40	0·39	8·57	0·48	8·88	0·44	7·14	0·44	12·45	0·61
	14	54	6·50	0·28	11·27	0·52	9·94	0·42	9·26	0·34	6·83	0·39	14·42	0·46
	15	30	6·67	0·39	11·35	0·70	10·39	0·56	9·95	0·46	7·50	0·51	14·14	0·62

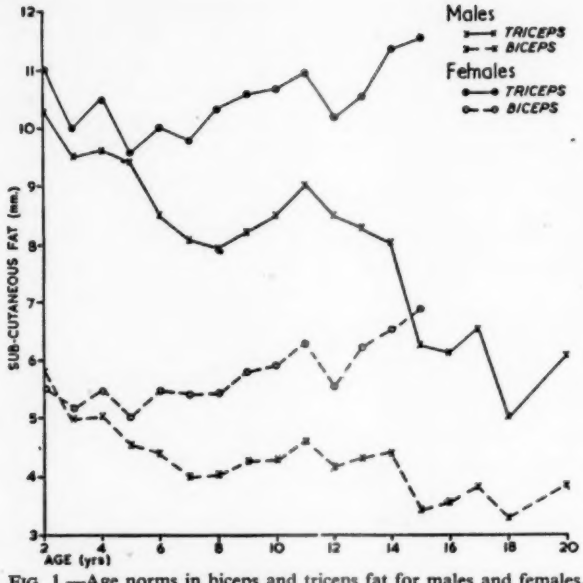

FIG. 1.—Age norms in biceps and triceps fat for males and females. Caliper pressure 10g./mm.²

trend of fat on the arm (Fig. 1) is to decrease to age 8 years, then to show a much slighter rise from age 8 to 11 years, and from 11 to fall slowly at first then more steeply to age 18 years. The difference in behaviour of trunk and arm fat in boys is unlikely to be due to selection. It may be due to a greater concentration of muscle activity in the arm region during late childhood than in early childhood, so depleting the fat there.

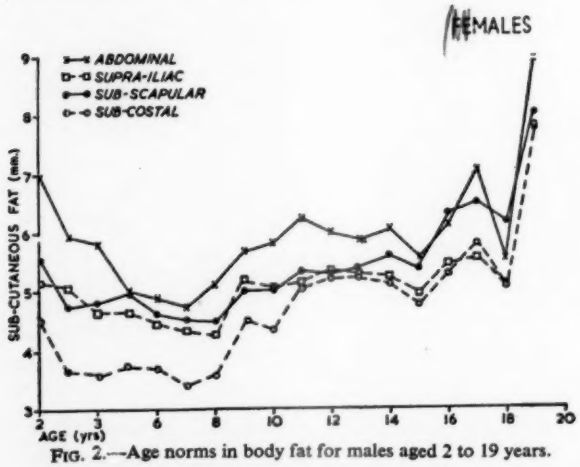

FIG. 2.—Age norms in body fat for males aged 2 to 19 years.

The caliper measurements are positively skewed, in some cases markedly so, and this has given rise to the suggestion of using a logarithmic transformation as is sometimes adopted in measuring weight, in order to produce a more nearly normal distribution (Edwards and others, 1955). The effects of skewness on the interepertation of measurements of fat is referred to below in the discussion.

RELATION OF CALIPER MEASUREMENTS OF SURFACE FAT TO TRUE FAT THICKNESS.—Since any caliper measurement of surface fat compresses the tissue (either by pressure from the instrument or by lifting the skinfold), the values obtained cannot be treated as absolute measures of fat thickness. However, the thickness of the subcutaneous fat can be measured from soft x-ray photographs involving no compression of the tissue.

I have calculated the following regression equation for the actual thickness of surface fat measured from x-ray plates in terms of the caliper measurement taken at the same sites*.

Actual subcutaneous fat thickness (mm.) = $0{\cdot}88\ x - 0{\cdot}00074\ x^2$, where x = actual M.R.C.

*Calculated from data kindly provided by Dr. J. M. Tanner and Mr. R. H. Whitehouse from the Harpenden Growth Study (Tanner, 1955).

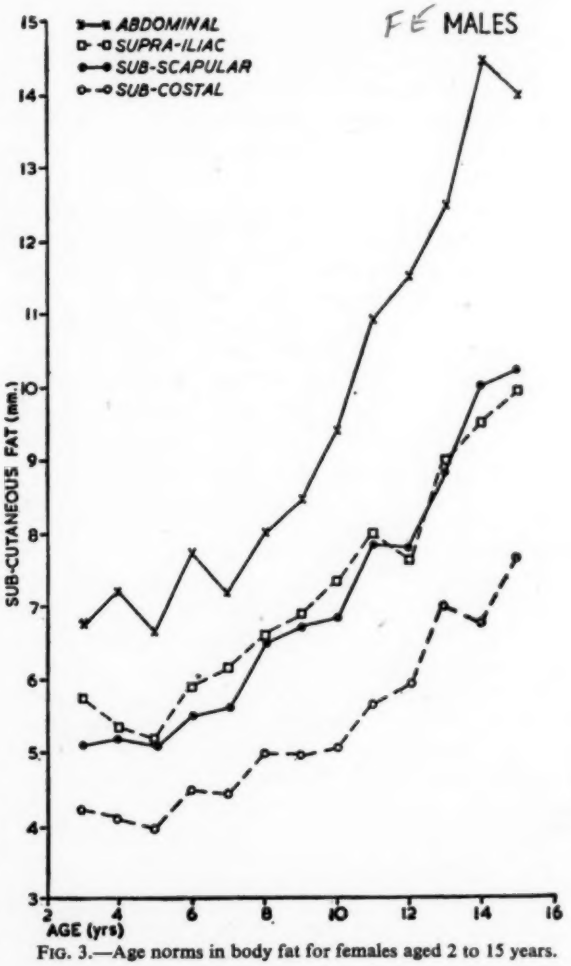

FIG. 3.—Age norms in body fat for females aged 2 to 15 years.

caliper reading. Fig. 4 shows the data in the form of a scatter diagram.

The same relation between caliper and *x*-ray results is given, whether the measuring site is over the biceps, triceps, or thigh, suggesting that though the fat compressibility differs with the amount of the jaw opening it is less dependent upon the site of the tissue measured.

A similar equation for the relation between the *x*-ray results and those obtained with the Franzen-type caliper, calculated from an accuracy trial held in 1952, gives results very close to those obtained by the double transformation from Franzen to British Indicators and from British Indicators to *x*-ray results.

Correlations between the Franzen-type caliper readings and the *x*-ray measurements were 0·82 and 0·89 for the thigh, 0·83 and 0·84 for biceps, and 0·89 and 0·90 for triceps, for boys and girls respectively.

The mean measurements at each age transformed to the equivalent true fat thicknesses as given by measurements obtained from *x*-ray plates are shown in Table V.

The figures in Table V seem to be the best form in which to set out results, since they indicate a true fat

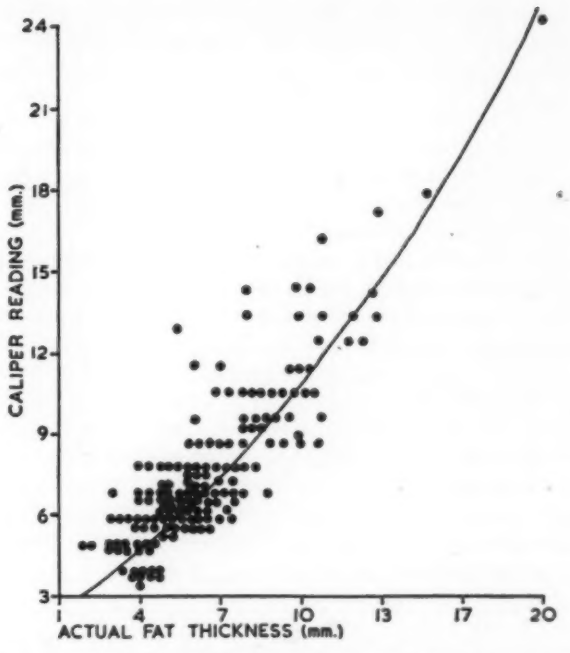

FIG. 4.—Relation between caliper readings of fat thickness and actual fat thickness.

Fat = 0·95 x — 0·0074x^3, where x = reading in tenths of a millimetre

TABLE V

MEASUREMENTS OF BODY FAT AT DIFFERENT SITES (UNCOMPRESSED FAT THICKNESS)*

Sex	Age (yrs)	Number Examined	Measurement Site					
			Biceps	Triceps	Sub-scapular	Supra-iliac	Sub-costal	Abdominal
Male	2	89	5·29	9·23	5·25	4·82	4·23	6·40
	3	28	4·69	8·57	4·43	4·75	3·35	5·69
	4	43	4·64	8·59	4·48	4·32	3·27	5·51
	5	49	4·20	8·41	4·67	4·31	3·44	4·66
	6	399	4·01	7·69	4·28	4·09	3·40	4·61
	7	65	3·64	7·40	4·21	4·05	3·10	4·40
	8	65	3·56	7·11	4·16	3·99	3·24	4·83
	9	130	3·83	7·67	4·73	4·82	3·20	5·33
	10	472	3·76	7·66	4·74	4·75	3·98	5·52
	11	235	4·25	8·26	4·92	4·91	4·79	5·93
	12	162	3·80	7·87	4·90	4·92	4·92	5·69
	13	110	3·90	7·59	4·99	4·94	4·89	5·52
	14	1,056	3·88	7·42	5·24	4·93	4·87	5·73
	15	98	3·02	5·97	4·96	4·64	4·48	5·16
	16	68	3·11	5·90	5·95	5·15	4·96	5·79
	17	275	3·28	6·06	6·10	5·20	5·54	6·80
	18	181	2·81	4·51	5·75	4·70	4·84	5·23
	Adults	228	2·92	5·51	7·46	—	7·33	8·20
Female	2	46	5·09	9·83	—	—	—	—
	3	38	4·74	8·90	4·75	5·22	4·03	6·42
	4	44	4·99	9·34	4·90	5·00	3·90	6·78
	5	45	4·64	8·65	4·88	4·82	3·67	5·87
	6	39	5·10	9·30	4·98	5·34	4·34	7·14
	7	60	4·90	8·62	5·09	5·64	4·25	6·68
	8	21	5·05	9·23	5·88	6·07	4·77	7·56
	9	80	5·30	9·35	5·95	6·42	5·04	7·83
	10	88	5·37	9·44	6·15	6·64	4·78	8·56
	11	94	5·89	9·64	7·30	7·43	5·39	9·83
	12	68	5·34	9·21	7·09	6·90	5·64	10·16
	13	65	5·87	9·45	7·97	8·22	6·73	11·07
	14	54	6·15	10·13	9·10	8·52	6·45	12·60
	15	30	6·31	10·19	9·44	9·11	7·05	12·41

*Caliper results converted to equivalent *x*-ray measurement of subcutaneous tissue.

thickness; anyone using his own pattern of caliper has only to calibrate his results against *x*-ray photographs at the same sites to give comparable figures.*

EFFECT OF DIFFERENT CONDITIONS ON MEASUREMENTS OF BODY FAT.—The effects of sex and age on fat thickness at different measuring sites have already been shown in Table IV and Figs 1 to 3. The data have also been broken down in terms of nutritional grading (by means of a clinical examination), and into a general measure of social class (from the type of school which the children attended and the neighbourhoods from which they came).

The numbers in the poor nutritional grade are too low to justify setting out the mean measurements separately for each age, and, as we are not primarily interested in the age differences within these groups, the mean figures are given for different nutritional categories and social groups relative to the equivalent age standards.

Nutritional Status.—The nutritional criterion is two-fold, consisting either of those children among the general population who were downgraded at the clinical examination (for method see Adcock, Hammond, and Magee, 1947), or of special groups of children who were selected as suffering from general debility or as being undernourished and in need of special treatment.

*It might be thought that if caliper measurements have to be calibrated according to *x*-ray results it would be much better to use *x*-rays in the beginning. However, the *x*-ray figures are probably rather less reproducible than the standard caliper results and there are overwhelming practical advantages for caliper measurements in field studies, added to which the choice of measuring sites for *x*-rays is more limited.

All the groups classified as being poorly nourished are below the general average for their age, but it is interesting to find that the well nourished children frequently show much less difference from the standard, and in some groups are even thinner than the standard on average (Table VI).

Social Status.—The children were divided into three groups: a "superior" group, consisting of children attending fee-paying day and boarding schools, whose parents belonged mostly to the professional classes; a "good" group, in which the children attended better-class schools in prosperous neighbourhoods and whose parents were mostly from Social Class III; and a "poor" group, drawn from children of Social Classes IV and V in "slums."

It is noteworthy that those from the poorest districts always give mean results below the standards for their age, but occasionally children from the highest social class give lower results than those from the good average group. There is certainly no social gradient in body fat comparable with that in weight and height in school children (Table VII, opposite).

CALCULATION OF AMOUNT OF BODY FAT.—The above results, which are given in the form of caliper measurements, are suitable for comparative purposes, but it would be useful to be able to calculate the actual weight of surface fat present, so that actual losses or gains could be calculated, *e.g.* in periods of stress. In principle, the measurement of the uncompressed thickness of surface fat and the areas of the body over which these thicknesses apply are all that are required, but in practice, many fat

TABLE VI

SKINFOLD FAT MEASUREMENTS FOR DIFFERENT NUTRITIONAL GRADES

Sex	Age Group (yrs)	Nutrition	Number Examined	Measurement Site					
				Biceps	Triceps	Sub-scapular	Supra-iliac	Sub-costal	Abdominal
Male	5–10	"Poor" ..	34	3·93	7·35	4·31	4·10	3·85	4·75
		"Good" ..	27	4·92	9·70	5·85	5·93	3·95	6·78
		Standard ..	—	4·00	8·00	4·70	4·50	3·90	5·20
	11–15	"Poor" ..	37	3·76	6·15	4·01	3·78	3·37	4·00
		"Good" ..	27	4·81	9·21	5·95	5·52	4·34	7·13
		Standard ..	—	4·26	8·33	5·30	5·22	5·15	6·00
Female	5–10	"Poor" ..	46	4·70	7·16	5·06	5·00	3·00	4·85
		"Good" ..	28	5·58	12·28	5·99	7·30	6·25	7·88
		Standard ..	—	5·36	9·85	5·80	6·20	4·77	7·95
	11–15	"Poor" ..	60	5·05	8·28	6·28	6·48	5·06	9·40
		"Good" ..	30	6·04	10·26	7·71	8·31	6·72	12·19
		Standard ..	—	6·15	10·58	8·48	8·38	6·66	12·60

measurements and many measurements of lengths and girths of different parts of the body are required. However, we can make use of the fact that fat measurements taken at a few sites are related closely to those at most sites, and hence we can estimate thicknesses at some of the sites. Further, we can estimate the total surface area, *e.g.* from Du Bois (1936) or from similar formulae, and "weight" this by a simple or weighted mean of the fat thicknesses throughout the body (the weights being determined by the area of the body over which the thickness applies). Experiments now being carried on, if confirmed, indicate that estimations of surface body fat sufficiently accurate for practical purposes can probably be made from a few measuring sites used in conjunction with weight and height and a very few additional body measurements.

Discussion

The measurements of skinfold thickness at any one site can be used for comparative purposes in nutritional or anthropometric surveys, just like any other measurements. However, the main justification for using skinfold measurements depends on whether the information they give applies to surface fat generally rather than to the particular sites measured. The experience obtained with such measurements over the past 10 years and the published work of Brožek and Keyes (1951) and of Edwards (1950) indicate that the pattern of fat deposition which applies to any one site applies closely to all other sites. The present paper has given a measure of the general influences operating, in the form of the percentage of the variance due to a common or general factor influence and the multiple correlations between combinations of a few measurements and total body fat. The contribution of the general influences is far higher than in any other anthropometric measurements. Thus, for example, one fat measurement will indicate far more about the general amount and distribution of body fat on a person than one physical measurement will tell us about a person's general size and shape. This is a finding of great practical importance, because it means that only a very few sites need to be measured in order to compare the general amount of body fat of persons or groups. It is doubtful whether any improvement in the representativeness of the measures for general nutritional purposes which might result from new combinations of sites would justify more intensive research into this problem. However, for studying clinically the changes in the distribution and amount of body fat which may occur with age, or with special diets, and so on, differences in the pattern of fat deposition may be important, and many more sites may then need to be measured. The sites used in this study are among those which have proved most convenient to take in the field.

Table VII

SKINFOLD FAT MEASUREMENTS FOR DIFFERENT SOCIAL LEVELS

Sex	Age Group (yrs)	Social Grade	Number Examined	Measurement Site					
				Biceps	Triceps	Sub-scapular	Supra-iliac	Sub-costal	Abdominal
Male	5–10	"Superior"	27	4·08	9·21	4·90	5·08	4·56	5·13
		"Good" ..	184	4·34	8·48	5·09	5·00	3·92	5·40
		"Poor" ..	93	3·52	6·89	4·16	4·11	—	4·28
		Standard ..	—	4·06	8·00	4·70	4·62	3·88	5·23
	11–15	"Superior"	160	4·17	8·57	5·90	5·77	6·31	6·76
		"Good" ..	50	4·47	9·36	5·40	5·57	—	6·59
		"Poor" ..	117	3·64	7·25	4·63	4·85	—	5·12
		Standard ..	—	4·07	7·94	5·30	5·17	5·09	5·91
Female	5–10	"Superior"	93	5·78	12·22	—	—	—	—
		"Good" ..	178	5·78	10·30	6·20	6·54	—	8·30
		"Poor" ..	103	4·46	9·07	—	—	—	—
		Standard ..	—	5·47	9·84	5·82	6·62	—	8·10
	11–15	"Superior"	137	6·64	12·38	—	—	—	—
		"Good" ..	50	6·35	10·70	7·52	7·90	—	11·03
		"Poor" ..	135	4·80	8·98	—	—	—	—
		Standard ..	—	6·12	10·60	8·03	8·32	—	11·88

The results for a particular measurement are not given unless the measurements were available for all children.

An admirable discussion of these and similar practical points is given by Edwards (1955).

The present standards are fairly complete for the younger age groups, although they should be regarded as purely provisional until more widespread measuring has been undertaken, *e.g.* by local health authorities. Figures covering the adolescent period in detail and different adult populations are particularly needed.

The distribution of caliper measurements of subcutaneous fat has been found to be positively skewed in much the same way as weight is skewed. Thus it is easily possible for a person to exceed the mean measurement by more than its own value at some sites, but he cannot be below the mean by this amount or he would have a negative thickness! The biological basis is that the fats apparently do not increase or decrease arithmetically; instead they appear to change proportionally, and therefore, as pointed out by Edwards and others (1950), a logarithmic transformation has some advantage. This is consistent with the "cellular" mechanism for fat deposition suggested by Edwards (1950). It is possible that the normal variability is being increased by the addition of what are really pathological cases (the obese children) in the population. The skewness probably has little effect on the interpretation of differences between group means since these mostly occur near the mode where the skewness is a minimum. However, a caution is necessary when considering very large measurements in the case of individual children. These should not be assumed to have the rarity which would apply to the corresponding $\frac{x}{\sigma}$ deviation in a normally distributed population. Since a logarithmic transformation gives an approximately normal curve, this can be used to compare the frequency of the logarithm of an actual measurement (and hence the corresponding absolute value). Alternatively, percentile points* of the data can be given when reporting fat measurements, provided that the numbers in the investigation are sufficient for the purpose. However, I think that it is more important to be concerned about an absolute level of fat in a child rather than with his position on an assumed distribution. The problem then becomes a clinical one of saying what is a suitable level beyond which body fat impairs functioning, *e.g.*, through extra strain on the heart or lowered mechanical efficiency, or in the case of leanness through affording insufficient thermal insulation. Extremes of body fat may also, of course, be associated with other pathological conditions, such as disorders of the endocrine system.

A further caution concerning the interpretation of fat measurements is perhaps relevant: the analysis of cross-sectional measurements in children (Hammond, 1953a) has shown that the major physical types consist of leptosomes and pyknics, and that subcutaneous fat over the arm is one of the main type differentiators; subcutaneous fat has much higher saturation with the type factor than has weight, for example. In this paper it is also shown that whilst there is evidence that the leptosomes (especially if they are also small) tend to be more often clinically inferior in the sense of being downgraded more often and showing more clinical signs indicative of inadequate nutrition—yet the great majority of leptosome children are healthy and we should take this as a warning not to regard a low fat measurement as a necessarily adverse sign. A recent or sudden loss of body fat is much more important than general thinness. Nevertheless, standards of body fat at different ages provide a useful guide in selecting children for special investigation and treatment.

I should like to advocate the method of expressing fat measurements relative to the *x*-ray thickness of uncompressed fat. This seems to me to be the most logical form of standardization, and it is superior to any standardization in terms of a particular design of instrument. For, however good that instrument may be, or however widely it may be used, there is still an element of compression of the skinfold and, moreover, of compression which may differ at different thickness readings.

Summary

(1) Results of measuring subcutaneous fat at different sites on the body have been correlated with each other to see which sites are the most representative of those measured, both in respect of the total subcutaneous fat for the individual at any moment and in respect of changes in fat with age.

(2) Measures used for indicating the degree of agreement are the correlations between each site and the sum of all the sites measured, and also the saturations for the general factor for surface body fat.

(3) All the measurements were found to be highly representative of total fat. When used in combination, the best measurements for determining total fat were those taken at the biceps or triceps plus those at the sub-scapular and abdominal regions.

(4) Standards for body fat measurements based on over 4,500 subjects calibrated according to M.R.C. calipers of plate size 6 × 15 mm. and

*It is possible to use a logarithmic transformation as a device for smoothing an observed distribution, and the calculation of percentiles can then be made and translated back into actual fat values based on such smooth curves. Alternatively, simple graphical smoothing of observed results can be used.

pressure 10 g./mm.^{2} for boys and girls from age 2 years upwards are given for biceps, triceps, subscapular, sub-costal, supra-iliac and abdominal regions. Standard errors at the different ages are also included.

(5) The caliper measurements have been transformed into equivalent actual fat thickness as measured from *x*-ray photographs.

(6) Mean measurements for different nutritional and social groups descend from good to poor nutrition and from high to low social class, but the highest groups in both cases show little difference from the age standards.

(7) The frequency distribution of subcutaneous fat measurements is positively skewed, and it is suggested that this may be partly due to the inclusion of a condition of obesity acting as a separate entity. Research is needed to differentiate over-fat or over-thin children on clinical grounds of health and optimal functioning.

(8) Methods of estimating the total quantity of subcutaneous fat in the body from measurements of surface area and a representative set of caliper measurements are being studied.

I should like to express my indebtedness to Drs. W. T. C. Berry and P. J. Cowin for permission to include many of their measurements of body fat in the Table of Norms. I am also most grateful to Dr. J. M. Tanner and Mr. R. Whitehouse for making available the extensive series of comparisons between caliper and *x*-ray measurements obtained during the Harpenden Growth Study from which I calculated the regression equation. Dr. D. A. W. Edwards has also very kindly allowed me to make use of his data on fat measurements in women. From these the National Physical Laboratories calculated the Tables of Correlations which I have analysed. I should also like to acknowledge the help given by Dr. E. R. Bransby in organizing the field trials, and for helpful criticism throughout the investigation.

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APPENDIX

MEASURING SITES

Forearm: Lateral surface half-way along.
Forearm: Proximal surface half-way along.
Biceps: Median line over middle of biceps.
Upper Arm: Lateral, midway between acromial edge and olecron.
Triceps: Half-way down the back of the arm over the triceps.
Triceps; Top of triceps.
Sub-scapular: Immediately below inferior angle of scapula following the natural fold at an angle approximately 45° to the vertical.
Inter-scapular: Between lowest points of scapulae.
Supra-iliac: Immediately above the left iliac crest.
Sub-costal: Immediately under the costal margin vertically below the nipple.
Abdominal: About 1 inch to left of and below umbilicus.
Lower Leg: Lateral, below head of tibia.
Under Chin:
Thigh: Median line 2 in. above patella.
Thigh: Mid-thigh lateral.
Pectoral: Below clavicle in nipple line.

CORRIGENDUM

In an article by Kirk, Shield, Stenhouse, Bryce and Jakobowicz, *Brit. J. prev. soc. Med.* (1955), **9**, 104, in the heading of Table VII on p. 108 for χ^2, read χ.

Brit. J. prev. soc. Med. (1955), 9, 212–213

A NOTE ON MONGOLISM IN TWINS

BY

ALWYN SMITH

From the Department of Social Medicine, University of Birmingham

It has often been thought that if one member of a pair of twins is a mongol, the other member is always affected if the pair is monozygous, and rarely affected if the pair is dizygous. This view is based on the absence of any report of monozygosity in a discordant pair. However, little evidence is available, since few of the pairs that have been recorded may be accepted unreservedly as monozygous. In the absence of direct evidence the matter can be examined by considering (*a*) the frequency of concordance among affected pairs, and (*b*) the numbers of affected pairs that are of like and of unlike sex.

The present report is based on 129 pairs in which sex, number affected, and diagnosis are believed to be reliably recorded. One hundred and seven were assembled by Øster (1953) and sources of a further 22 pairs are given in the Appendix. Nineteen of the latter were reported in the literature; the remaining three pairs are now reported for the first time:

(*a*) Table I shows the distribution according to sex of 152 affected in 129 pairs. Acceptable evidence of dizygosity is recorded for three of 23 pairs in which both twins are affected (MacKaye, 1936; Gordon and Roberts, 1938; Jervis, 1943). Even if it is assumed that all other concordant pairs are monozygous, the proportion (20/129 = 15·5 per cent.) is lower than estimates usually given for the proportion monozygous among representative twin pairs. Since the proportion of monozygous twins varies with maternal age, reaching its lowest value at the age quinquennium 35–39 years (Waterhouse, 1950), it is conceivable that this result may be due to the late maternal age at which many mongols are born. Maternal age is known for only 55 of the 129 pairs.

TABLE I
DISTRIBUTION OF AFFECTED TWINS

Type of Pair		Number in Discordant Pairs	Number in Concordant Pairs	Total Number of Affected
Like Sex	Males	31	20	51
	Females	31	26	57
Unlike Sex	Males	25	—	25
	Females	19	—	19
Total	Males	56	20	76
	Females	50	26	76

However, it is possible to estimate the maternal age distribution of affected twins from knowledge of the age distributions of unaffected twins and of a representative series of mongols. An estimate has been calculated from the distribution of 241 mongols born in the City of Birmingham during the 11 years 1942–52 (Smith and Record 1955a) and from the Registrar-General's figures for the maternal age distribution of twin maternities in England and Wales during the same years. Comparison of this estimated distribution with that for the small series of affected twins for which maternal age at birth was recorded (Table II) shows reasonable agreement.

TABLE II
MATERNAL AGE DISTRIBUTION OF AFFECTED TWINS

Maternal Age (yrs)	Under 20	20–24	25–29	30–34	35–39	40–44	45 and over	Total
Expected per cent.	0·5	5·1	13·9	18·9	34·1	26·1	1·4	100
Observed per cent.	1·8 (1)	5·5 (3)	14·5 (8)	9·1 (5)	36·4 (20)	25·5 (14)	7·3 (4)	100 (55)

Expected proportions of monozygous twins at each maternal age quinquennium have been estimated by Weinberg's method from data published by the Registrar-General for the 11 years for which data on mongol births were available. Application of these proportions to the estimated distribution by maternal age for affected twins gives a value for the expected proportion of monozygous pairs among pairs selected by the presence of an affected member. This proportion (26·3 per cent.) is greater than the proportion of concordant pairs for which there is no evidence of dizygosity (15·5 per cent.), the difference (10·8 per cent.) being more than 2·5 times its standard error (3·9 per cent)..

The above procedure is open to the criticism that twin pairs reported in the literature may be unrepresentative. It is probable, however, that selection will tend to favour publication of concordant rather than of discordant pairs.

(*b*) The expected numbers of like and unlike sexed pairs can be estimated in 109 presumptively dizygous pairs composed of 106 discordant pairs

(assumed to be dizygous) and three concordant pairs whose dizygosity was established. The sex ratio of affected twins is 50 per cent., so that the expected proportion of like sexed pairs is also 50 per cent. Table III shows that there is a significant excess of like sexed pairs. It therefore seems unlikely that all the discordant pairs are dizygous.

TABLE III
DISTRIBUTION OF PRESUMPTIVELY DIZYGOUS TWIN PAIRS

Sex	Like Sexed	Unlike Sexed	Total
Observed (*a*) ..	65	44	109
Expected (*b*) ..	54·5	54·5	109
Difference (*a*)–(*b*)	+10·5	−10·5	—

$\chi^2 = 4{\cdot}05$, $n = 1$, $p < 0{\cdot}05$

It is possible to estimate the probable number of discordant monozygous pairs by subtracting the number of unlike sexed from the number of like sexed discordant pairs. If the difference (18) is added to the number of concordant pairs for whom there is no evidence of dizygosity (20), the total (38) may be regarded as an estimate of the number of monozygous pairs. The proportion of monozygous pairs calculated from this estimate (38/129 = 29·5 per cent.) is very near the expected proportion of monozygous pairs (26·3 per cent.). The fact that it is slightly larger may be due to the selective reporting of concordant pairs.

An alternative explanation which should be considered is that foetal loss might account for the low proportion of concordant pairs. Some support for this possibility is provided by the observation (Smith and Record, 1955b) that threatened abortion may be more common in pregnancies that result in a mongol than in pregnancies that result in unaffected births. If the presence of one malformed foetus predisposes to abortion, the presence of two might increase the risk. Foetal loss in concordant pairs cannot, however, account for the excess of like sexed pairs among discordant pairs, and it is concluded that the data suggest that mongolism sometimes occurs in only one of a monozygous pair.

SUMMARY

To 126 reports of mongolism in one or both members of a twin pair are added three new pairs. The 129 pairs contained 152 affected. Reliable evidence of zygosity is available for very few.

The proportion of concordant pairs for whom no evidence of dizygosity is reported is significantly less than the expected proportion of monozygous pairs. If it is assumed that all discordant pairs are dizygous, they contain a significant excess of like sexed pairs. When the proportion of monozygous pairs among the reported pairs is estimated by Weinberg's method, it agrees well with the expected proportion of monozygous pairs.

It is suggested that the most likely explanation of these results is that some of the discordant pairs are monozygous.

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APPENDIX

SOURCES OF 22 TWIN PAIRS CONTAINING AT LEAST ONE MONGOL, NOT INCLUDED IN THE SERIES OF 107 PAIRS ASSEMBLED BY ØSTER (1953)

Author	Date	Sex of Twins	Remarks
Wieland	1927	**f f**	Stated to be monozygous
Arancibia and Fumasoli	1935	**m f**	
Jenkins	1936	**f m**	
Doxiades and Portius	1938	**f f** **f f**	
Gordon and Roberts	1938	**f f**	Dizygous (finger prints)
Harker	1942	**f f**	
Déchêne	1947	**f f**	
Cook	1950	**m f** **f m**	
Posteraro	1951	**m f**	
Robertson ..	1952	**m f**	
Lang-Brown, Lawler, and Penrose ..	1943	**f f** **f f** **m m** **m m**	Monozygous (blood groups) Dizygous (blood groups) Dizygous (blood groups) Dizygous (blood groups)
Morris and MacGillivray ..	1953	**f f** **m f**	
Young	1954	**m m**	Monozygous (blood groups and finger prints)
Not previously reported ..		**m m**	Dizygous (blood groups and finger prints)
Not previously reported ..		**m m**	Zygosity not examined
Not previously reported ..		**f f**	Zygosity not examined

Sex of affected twins is given in heavy type.

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